(12) **United States Patent**
Kishima

(10) **Patent No.:** **US 7,592,682 B2**
(45) **Date of Patent:** **Sep. 22, 2009**

(54) **OPTICAL WAVEGUIDE AND PHOTORECEPTOR**

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(73) Assignee: **Sony Corporation**, Tokyo (JP)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 54 days.

(21) Appl. No.: **11/562,519**

(22) Filed: **Nov. 22, 2006**

(65) **Prior Publication Data**

US 2007/0114630 A1 May 24, 2007

(30) **Foreign Application Priority Data**

Nov. 24, 2005 (JP) P2005-339467

(51) **Int. Cl.**
H01L 31/06 (2006.01)

(52) **U.S. Cl.** **257/462**; 257/E31.073; 257/E31.053; 438/197

(58) **Field of Classification Search** 257/462, 257/E33.076, E33.077, E31.053, E31.073, 257/E31.076, E31.079, E31.082; 438/197
See application file for complete search history.

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Nozawa, Tesuo; Increasing Penetration of optical transmission into a case of deice; Precedence by a roster or a portable telephone: Nikkei Electronics; Jun. 6, 2005; p. 59-p. 70.

* cited by examiner

Primary Examiner—Kiesha L Rose
Assistant Examiner—Tucker Wright
(74) *Attorney, Agent, or Firm*—Sonnenschein Nath & Rosenthal LLP

(57) **ABSTRACT**

A semiconductor device having a substrate that contains an insulating layer and a semiconductor layer provided on the insulating layer. The semiconductor also has an optical waveguide that is formed along a predetermined path. This optical waveguide is formed by making the semiconductor layer non-uniformed in thickness thereof. The semiconductor further has a photoreceptor having MISFET containing a floating channel body that is formed on a position of the semiconductor layer in which electric field of light guided inside the optical waveguide exists and a gate for forming channel formed on a front surface side of the channel body.

3 Claims, 22 Drawing Sheets

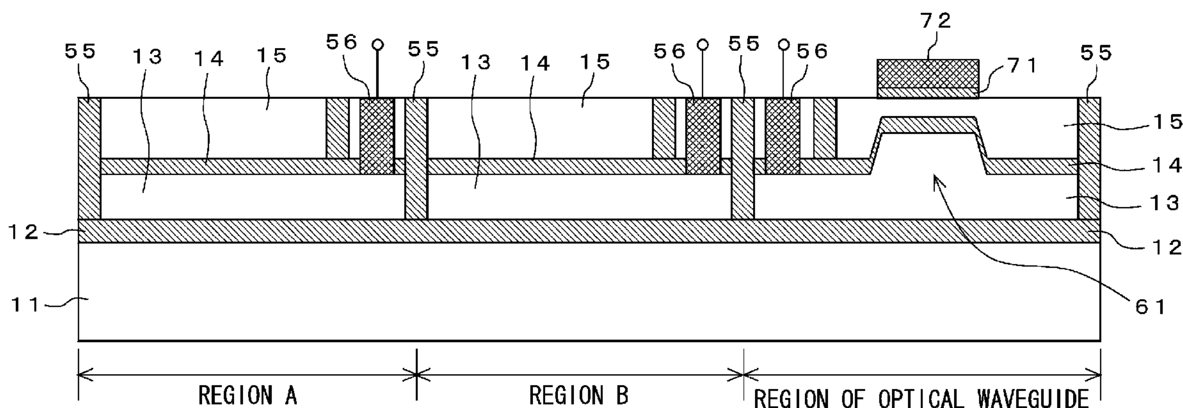


FIG. 1

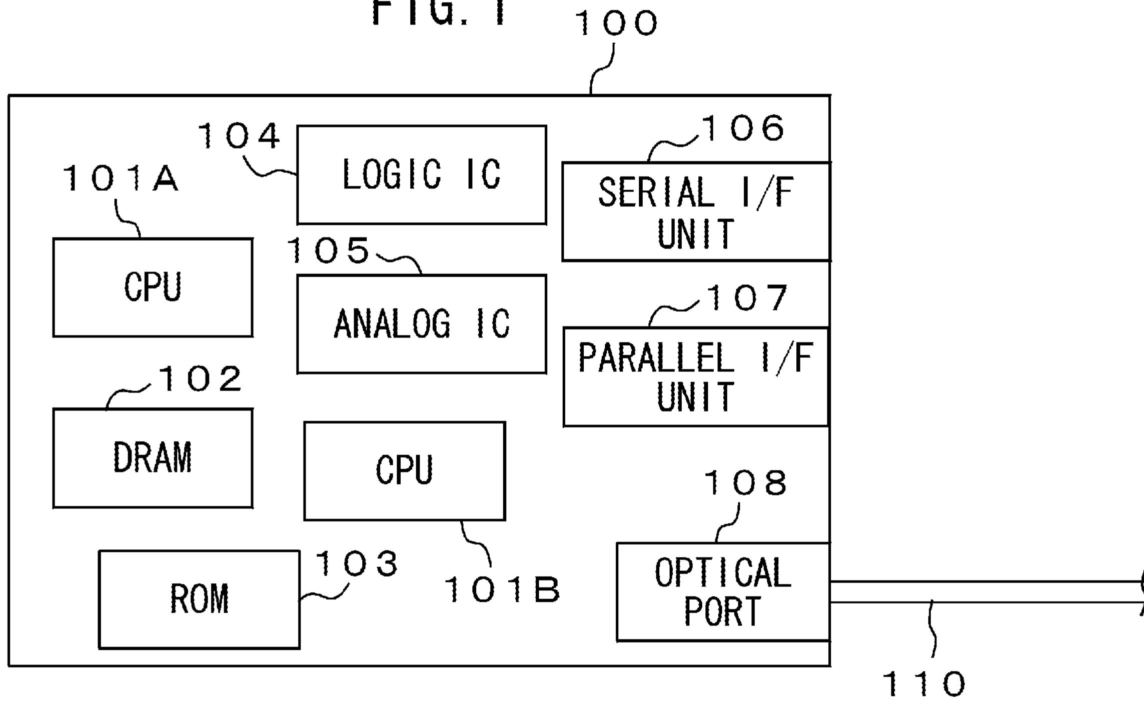


FIG. 2

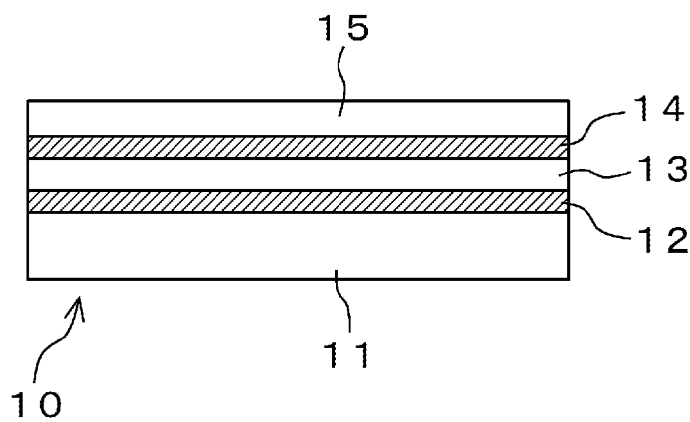


FIG. 3A

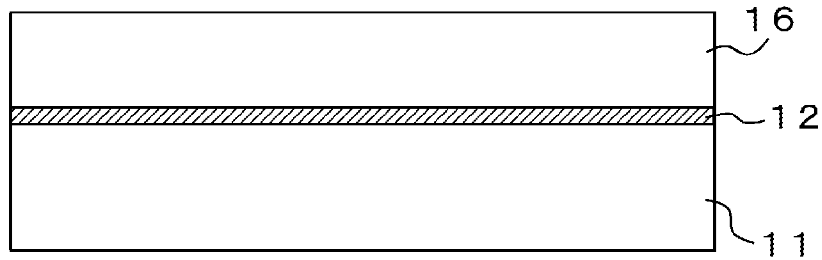


FIG. 3B

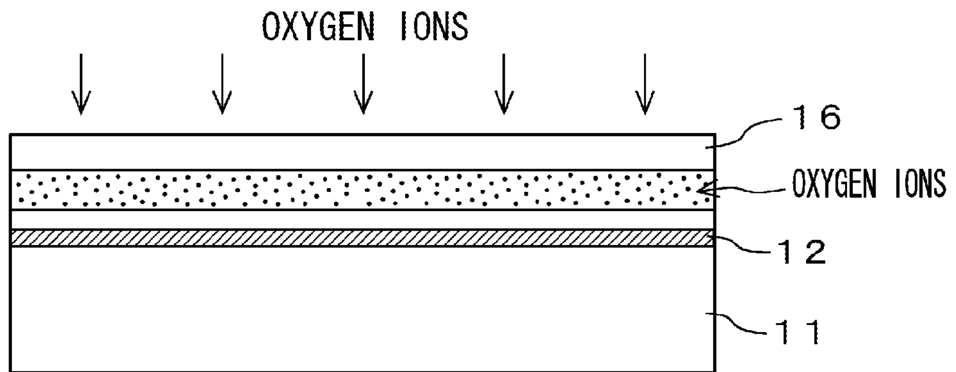


FIG. 3C

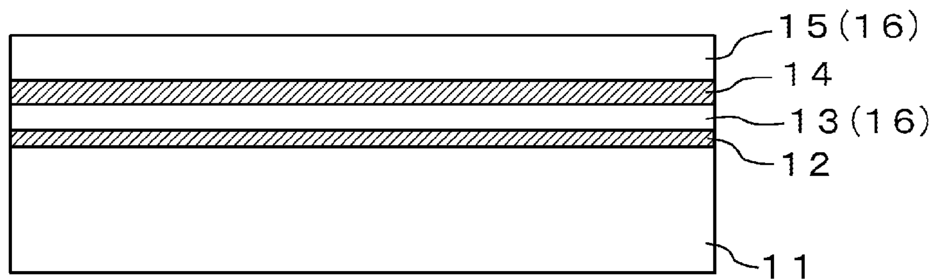
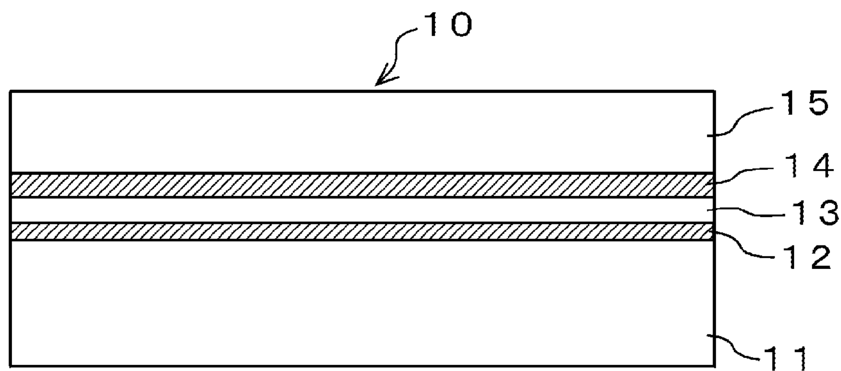


FIG. 3D



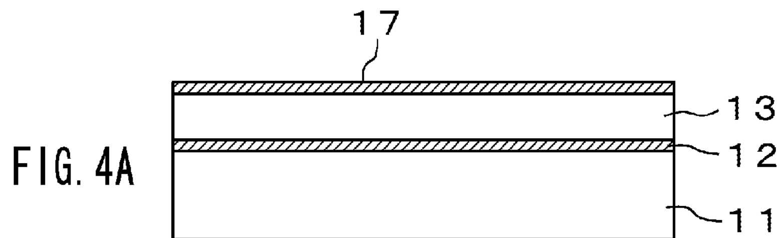


FIG. 4A

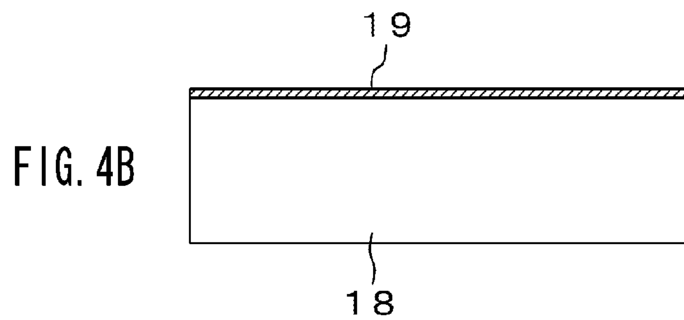


FIG. 4B

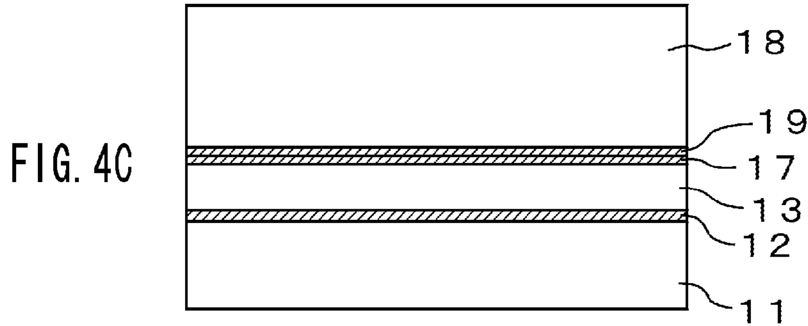


FIG. 4C

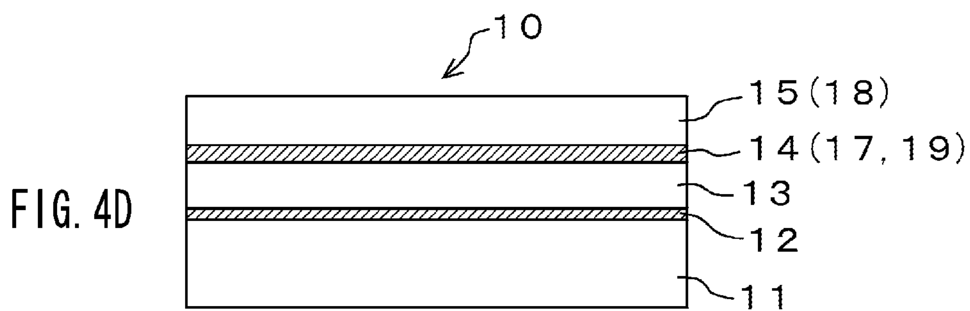
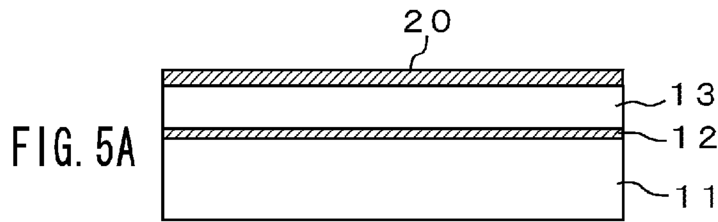
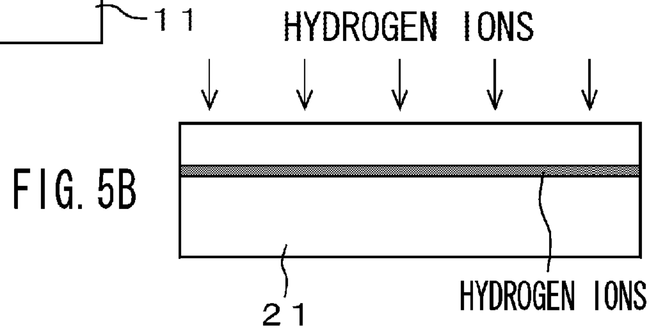


FIG. 4D


20
13
12
11
FIG. 5A


HYDROGEN IONS
FIG. 5B
21
HYDROGEN IONS

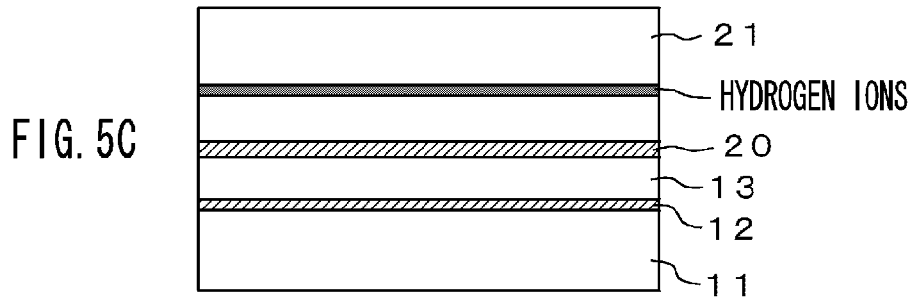
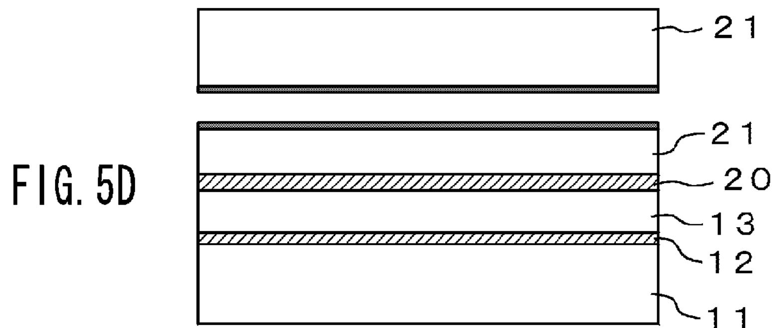


FIG. 5C
21
HYDROGEN IONS
20
13
12
11


21
FIG. 5D
21
20
13
12
11

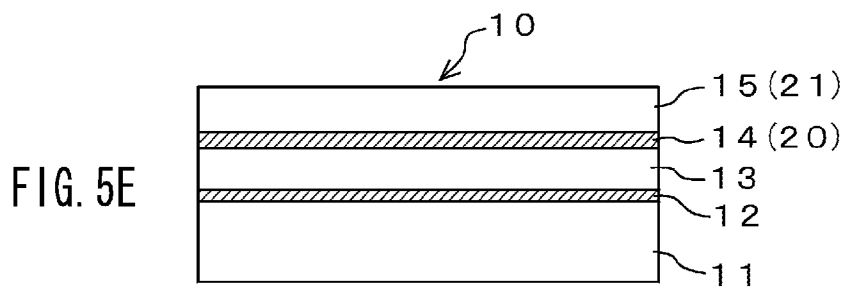

10
FIG. 5E
15 (21)
14 (20)
13
12
11

FIG. 6

MC
WL
45
BL
VL
46
44
47
49
48
n
p
n
50
50
12
13
15
14
11

FIG. 7

51
BL
BL
BL
50
VL
MC
WL
50
VL
WL
50
VL
WL

FIG. 8

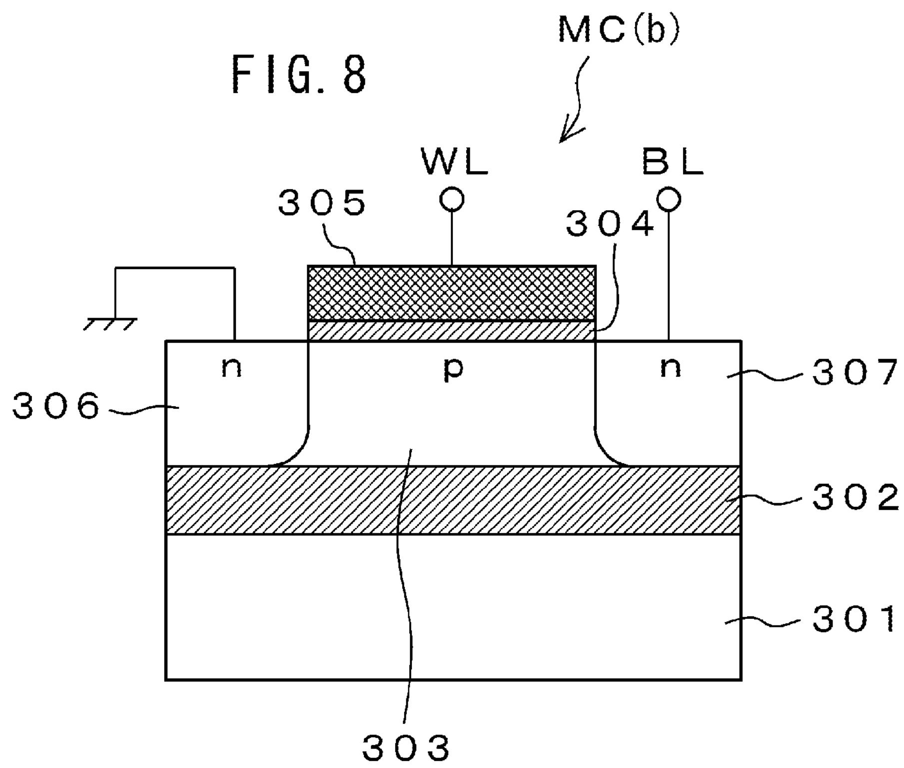


FIG. 9

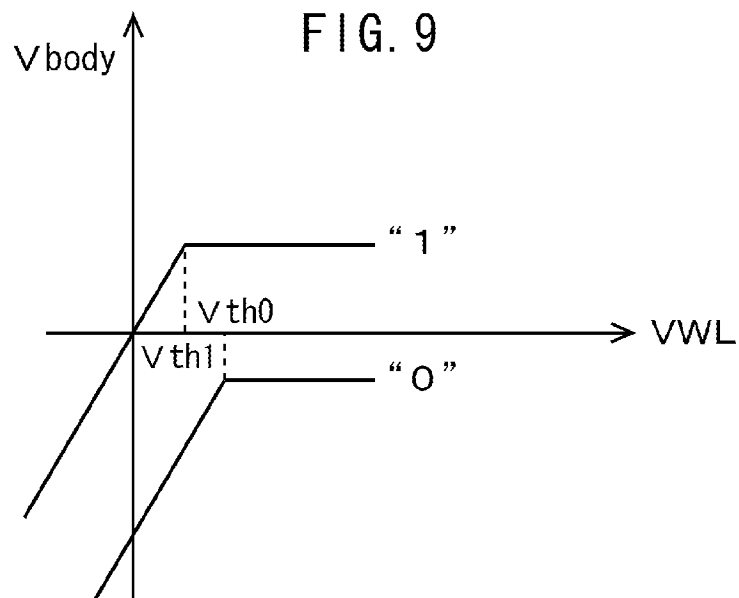


FIG. 10A

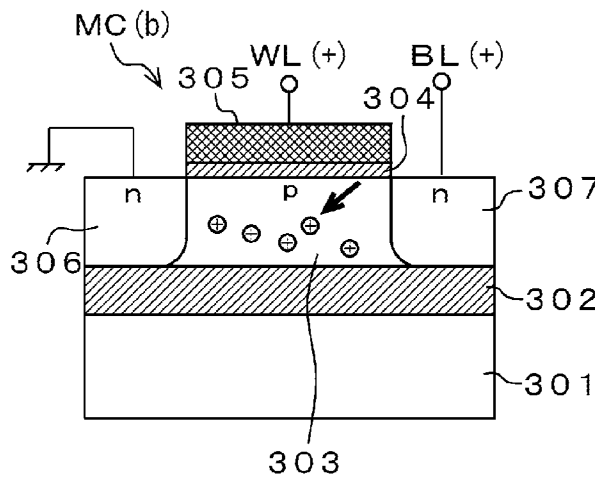


FIG. 10B

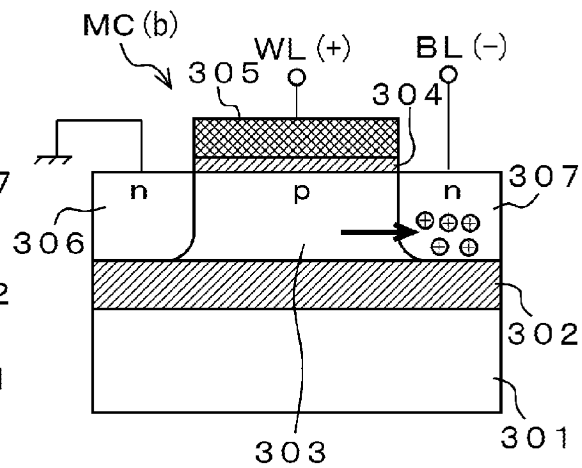


FIG. 11A

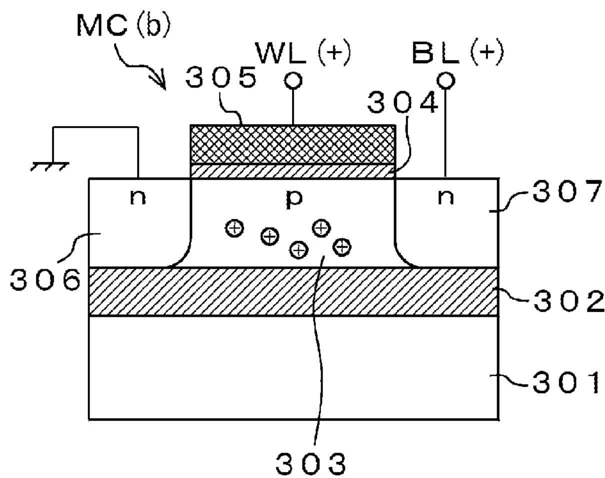


FIG. 11B

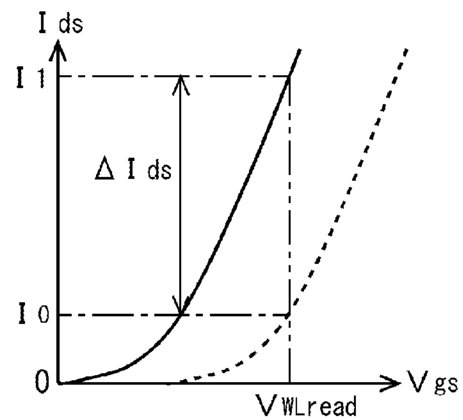


FIG. 12A

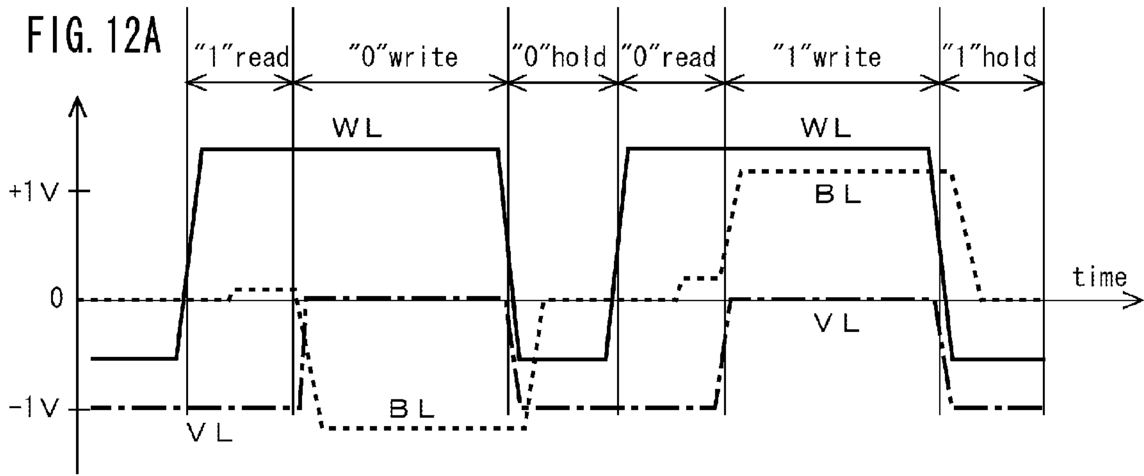


FIG. 12B

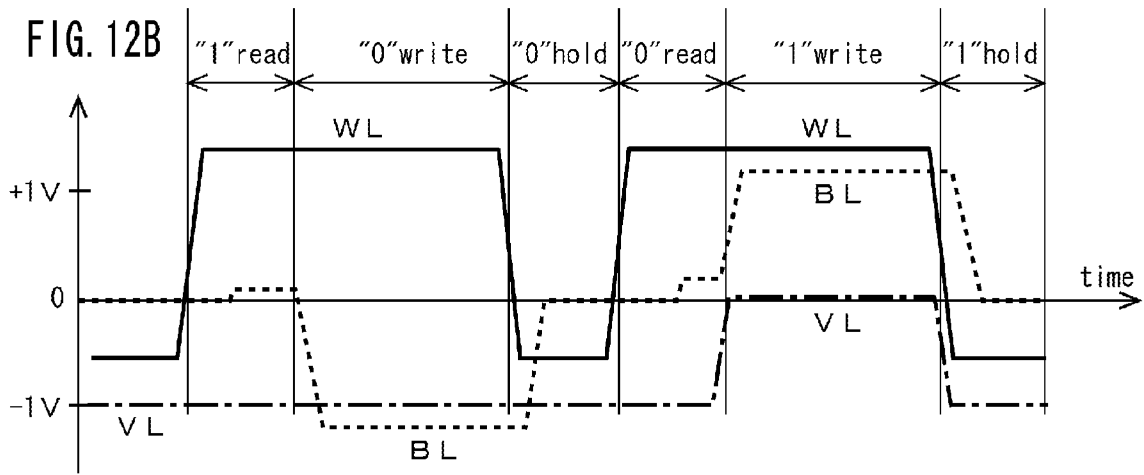


FIG. 12C

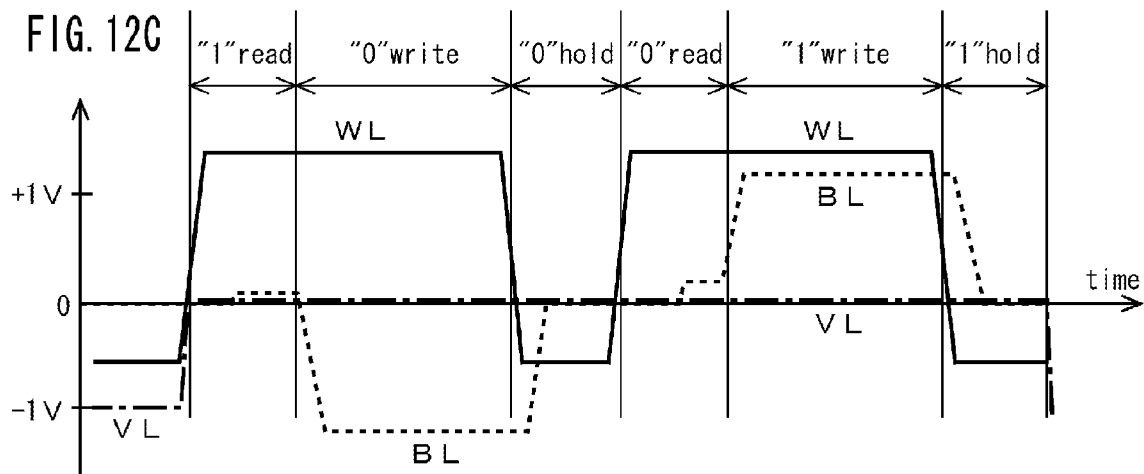


FIG. 13

REGION A

REGION B

REGION OF OPTICAL WAVEGUIDE

11 12 13 14 15 55 56 61 71 72

FIG. 14

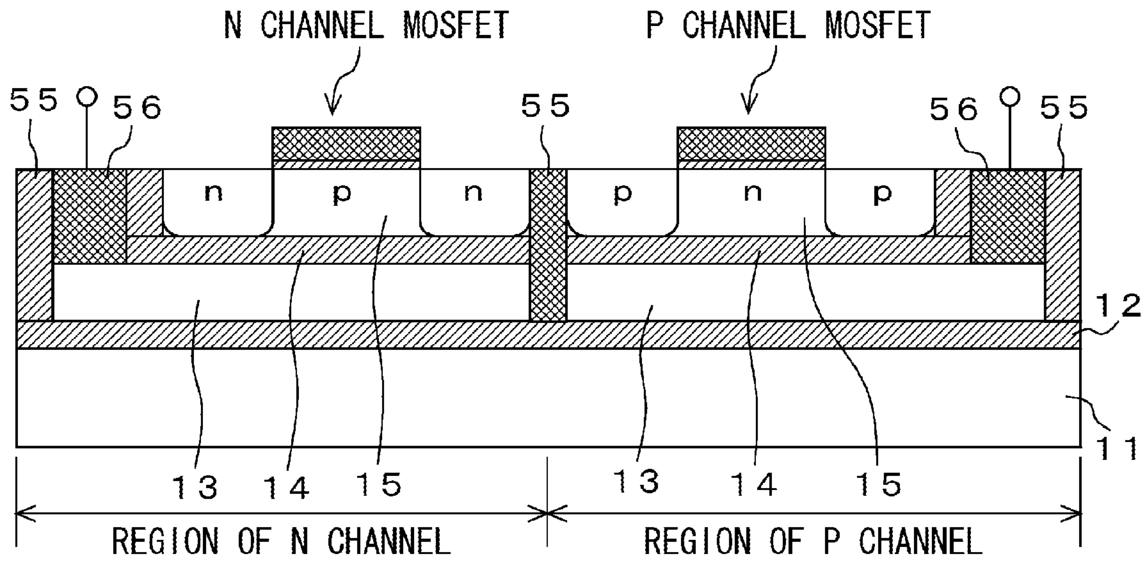


FIG. 15

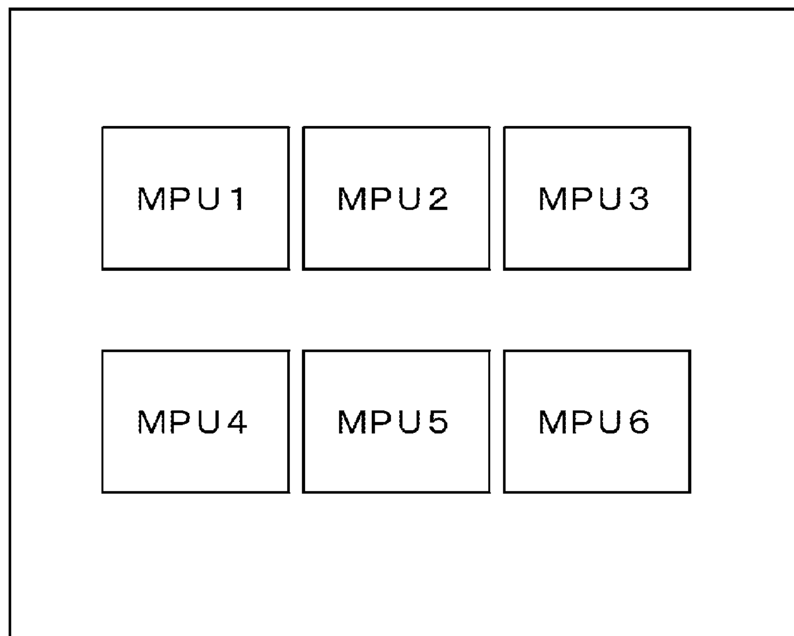


FIG. 16A

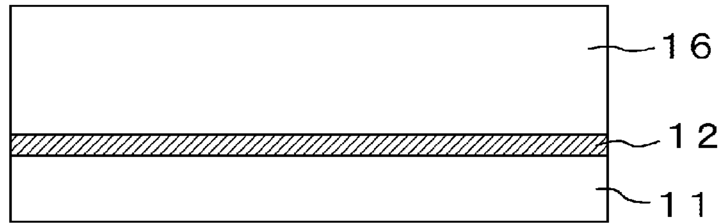


FIG. 16B

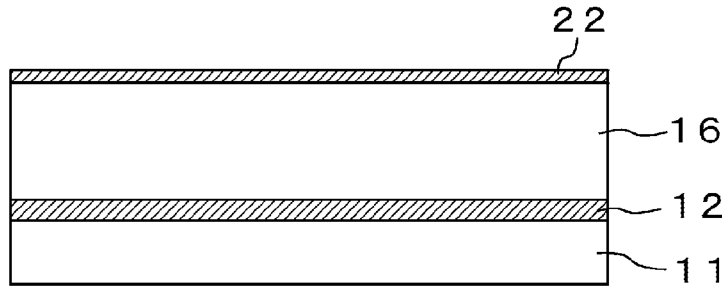


FIG. 16C

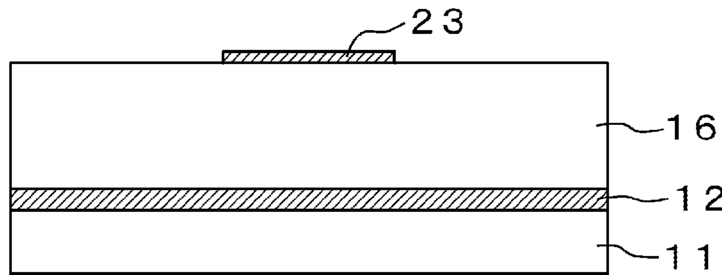


FIG. 16D

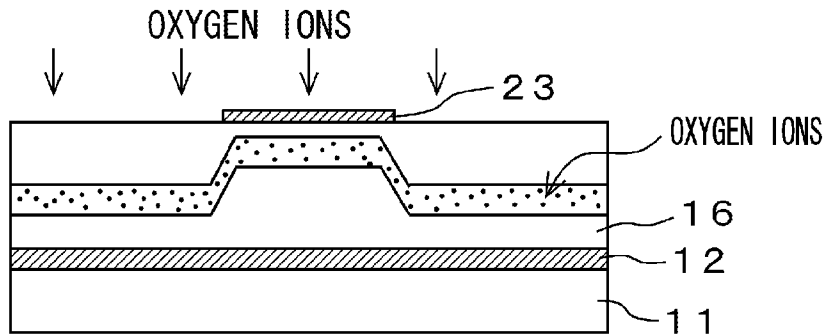


FIG. 16E

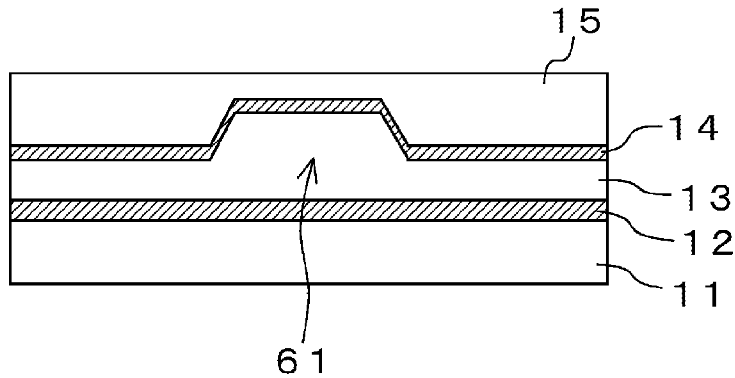


FIG. 17

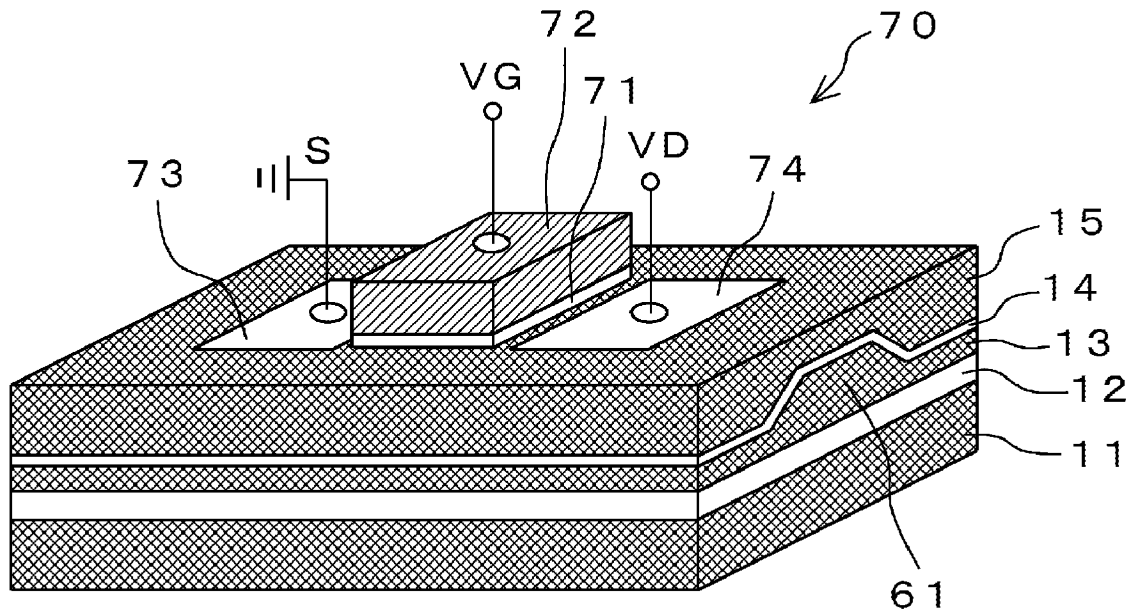


FIG. 18

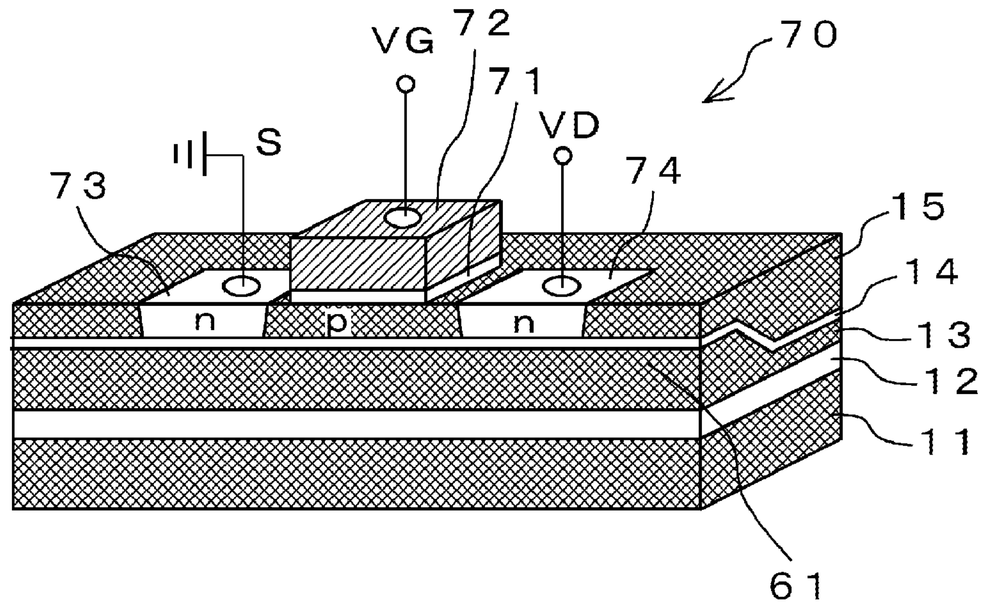


FIG. 19

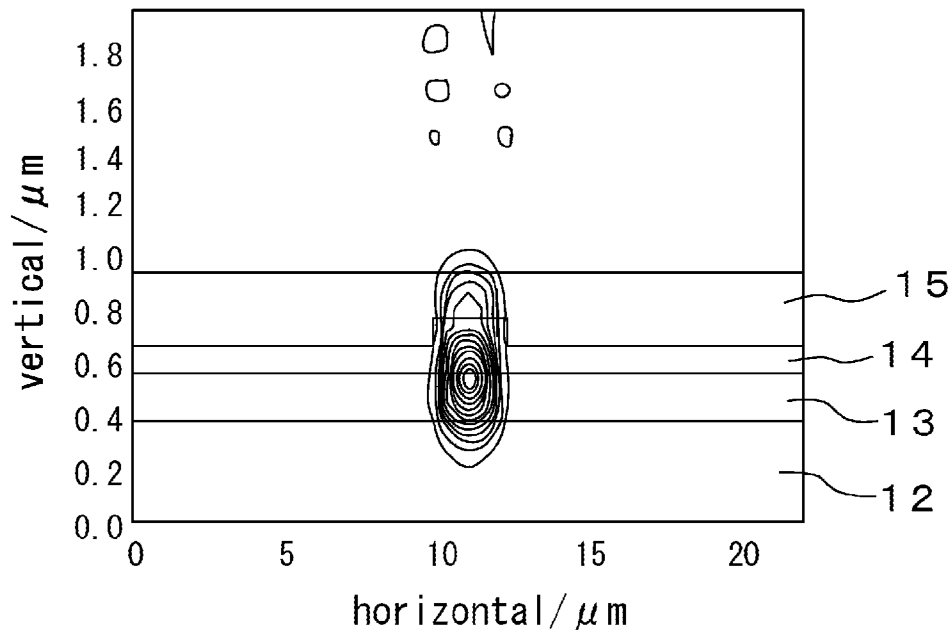
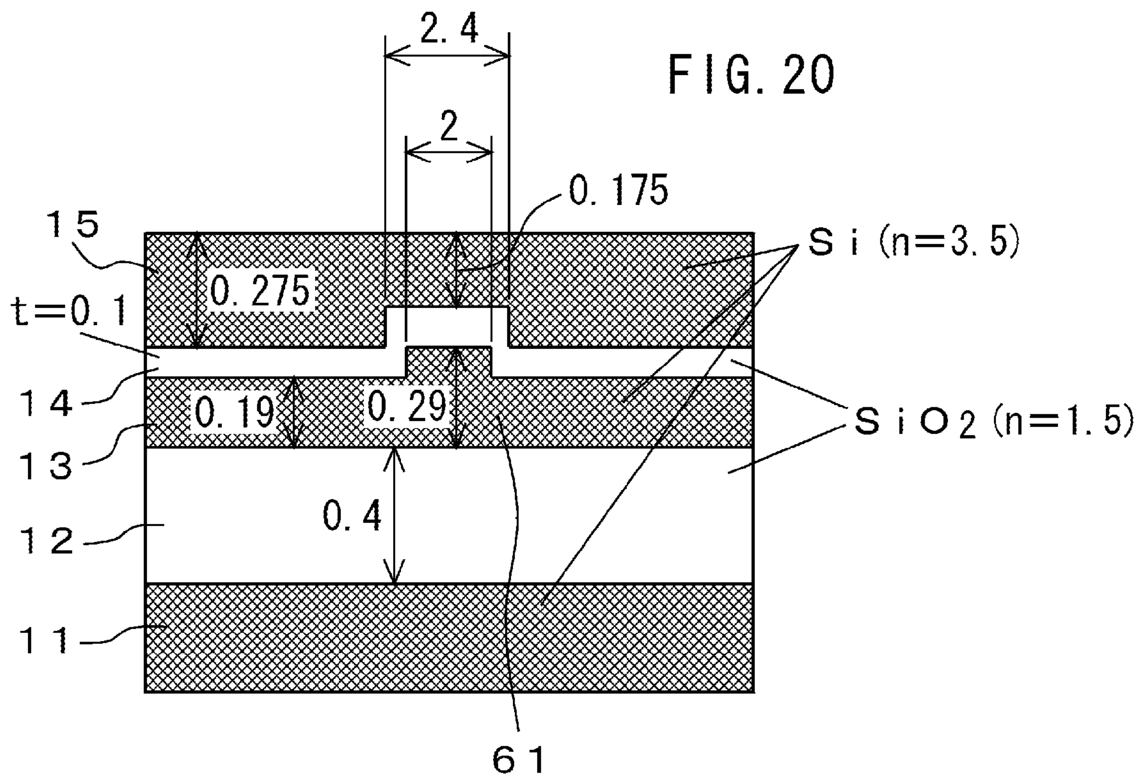


FIG. 20



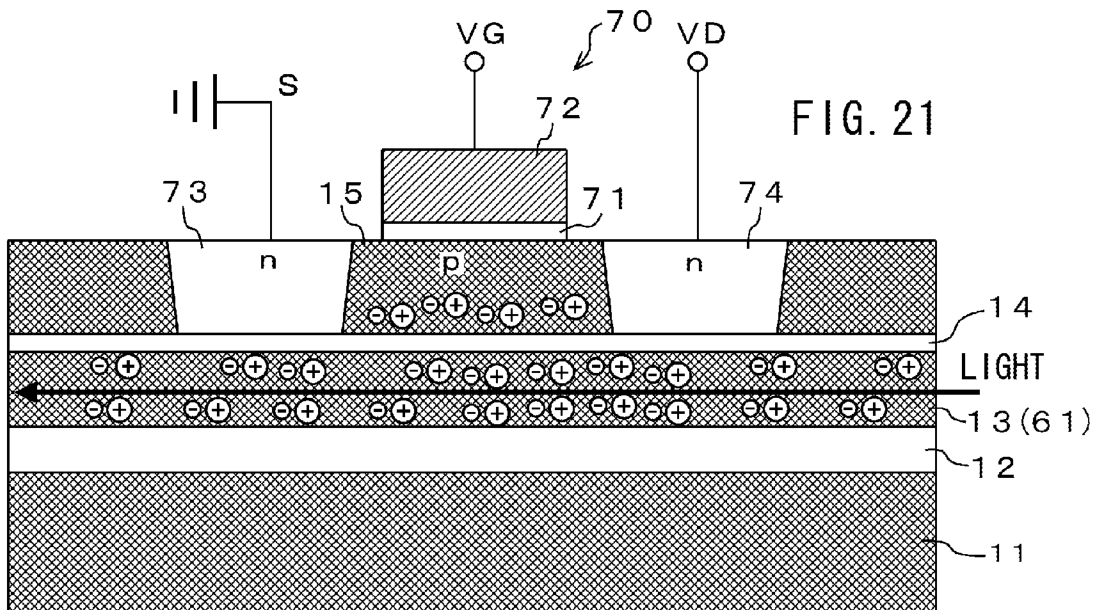


FIG. 21
70
VG
VD
S
72
73
15
71
74
n
p
n
14
LIGHT
13(61)
12
11

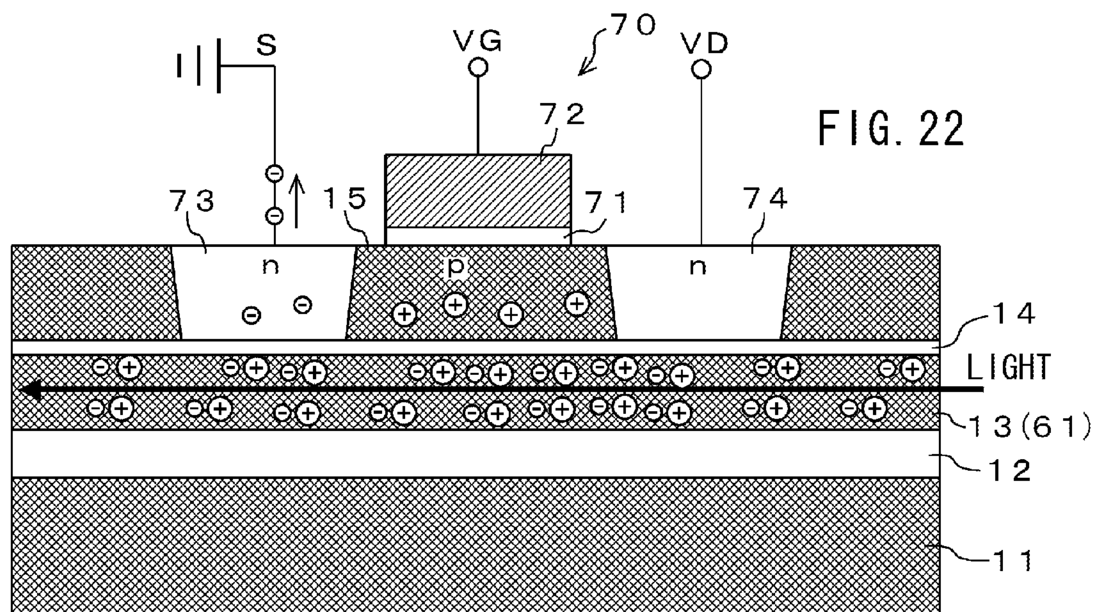
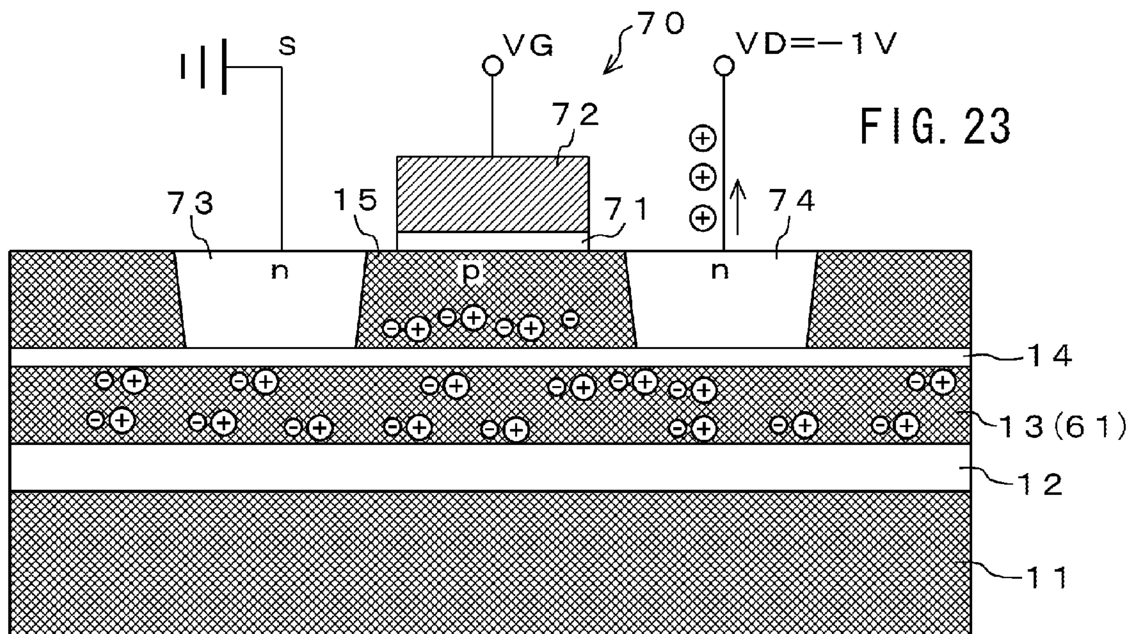
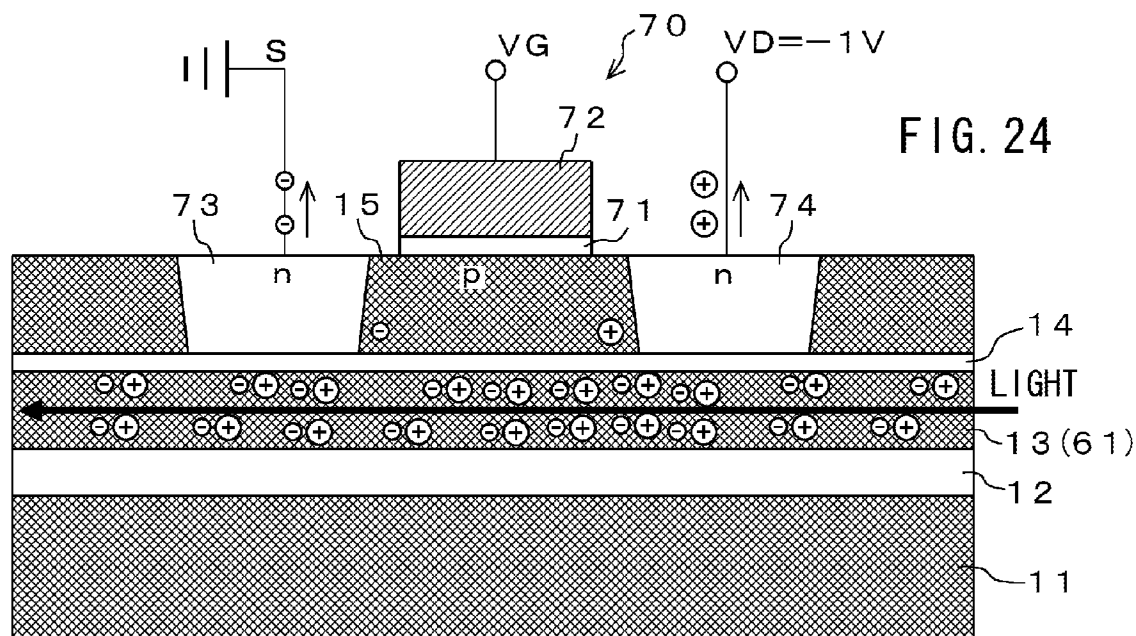
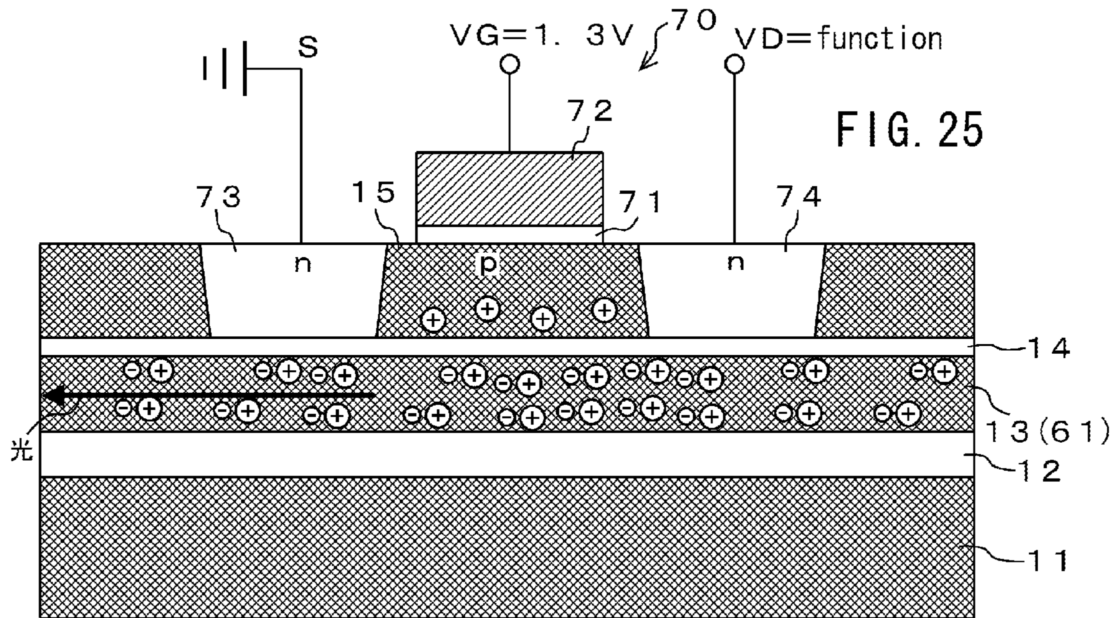


FIG. 22
70
VG
VD
S
72
73
15
71
74
n
p
n
14
LIGHT
13(61)
12
11


S
VG
70
VD=−1V
72
FIG. 23
73
15
71
74
n
p
n
14
13(61)
12
11


S
VG
70
VD=−1V
72
FIG. 24
73
15
71
74
n
p
n
14
LIGHT
13(61)
12
11


VG=1. 3V
70
VD=function
S
72
FIG. 25
73
15
71
74
n
p
n
14
光
13(61)
12
11

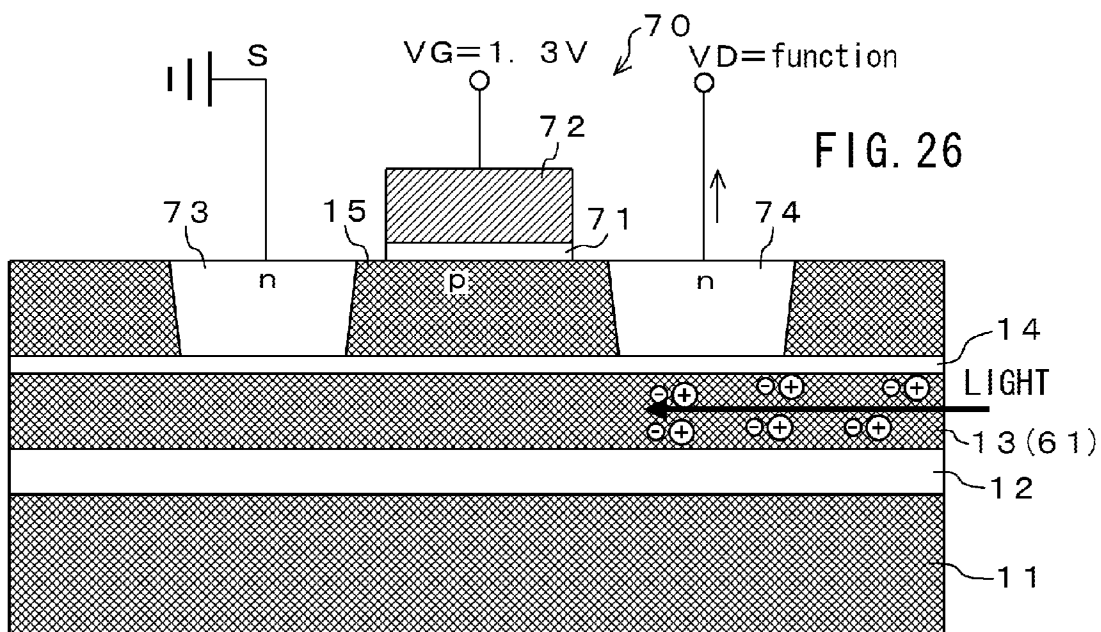

70
VG=1. 3V
VD=function
S
72
FIG. 26
73
15
71
74
n
p
n
14
LIGHT
13(61)
12
11

FIG. 27

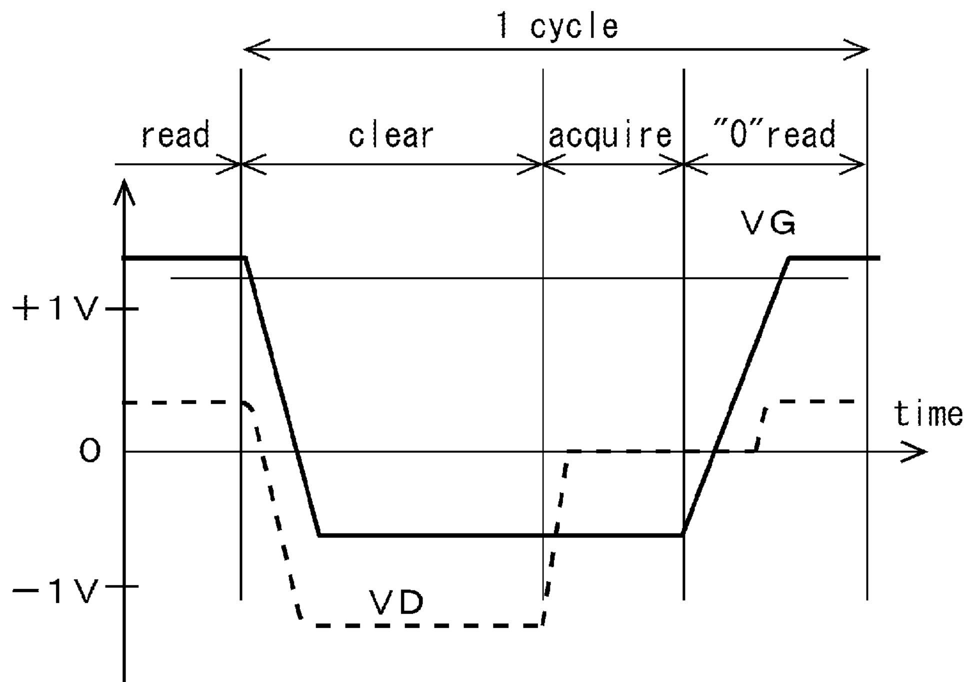
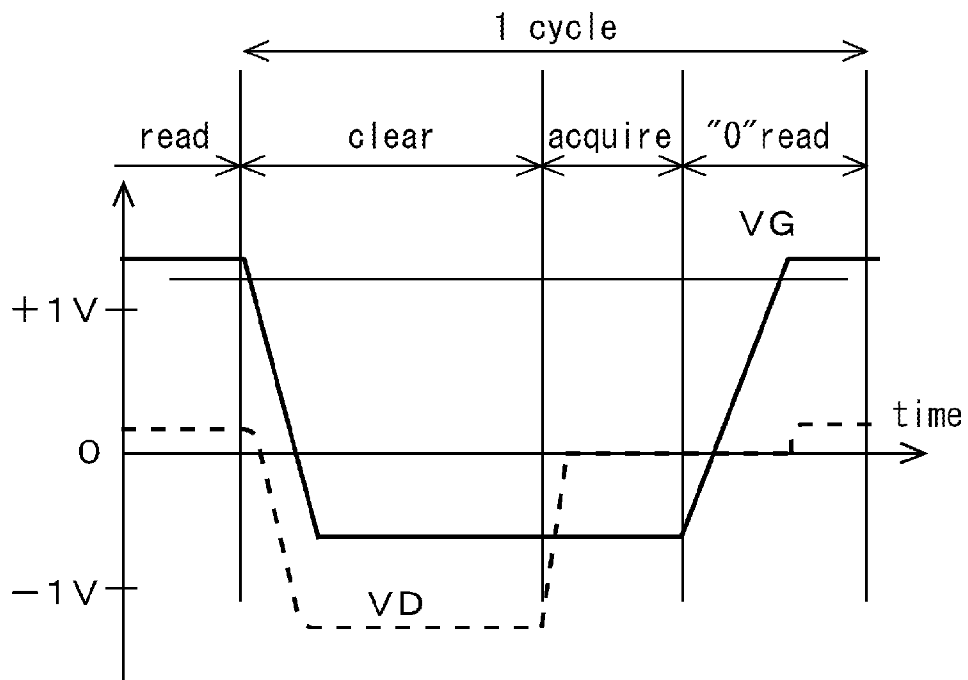


FIG. 28



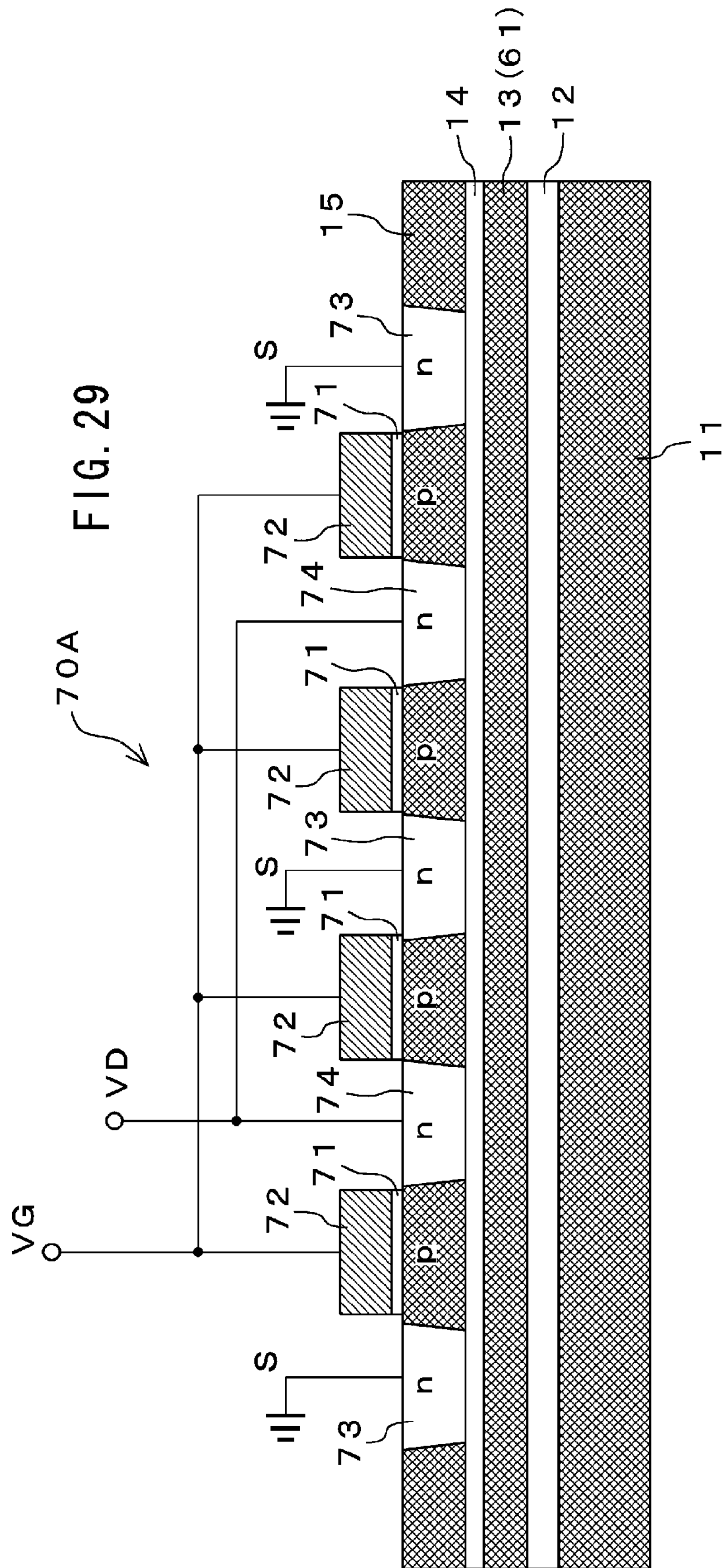


FIG. 29
70A
VG
VD
S
71
72
73
74
n
p
15
14
13 (61)
12
11

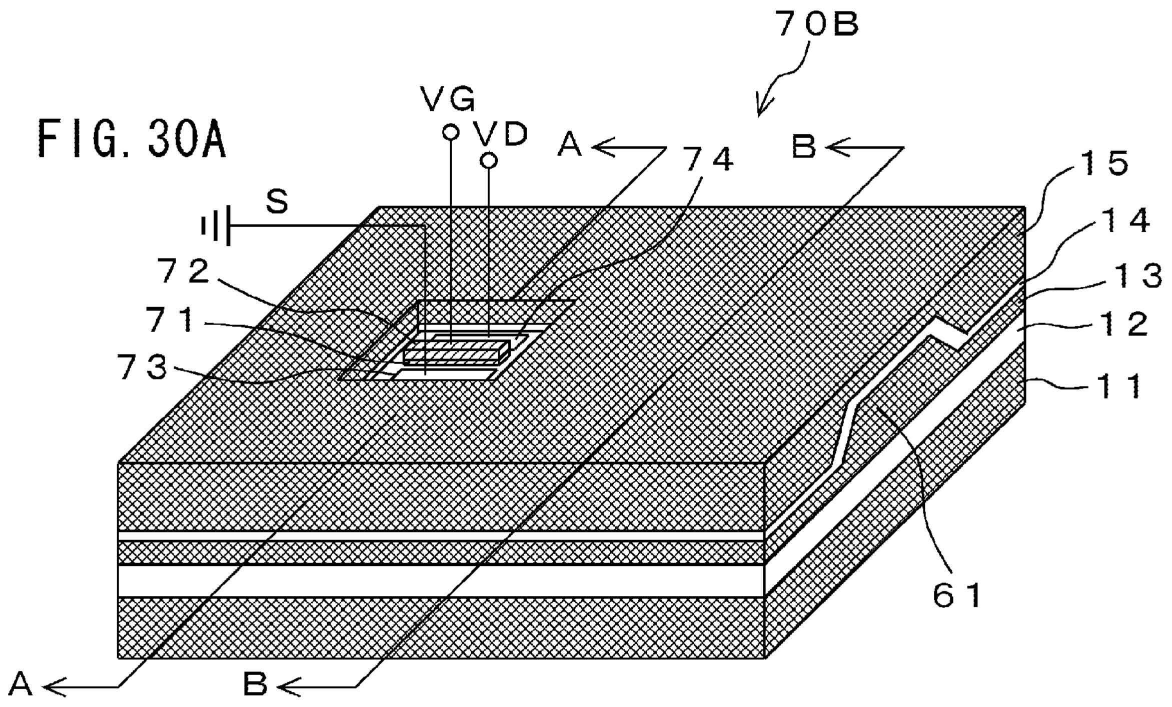


FIG. 30A

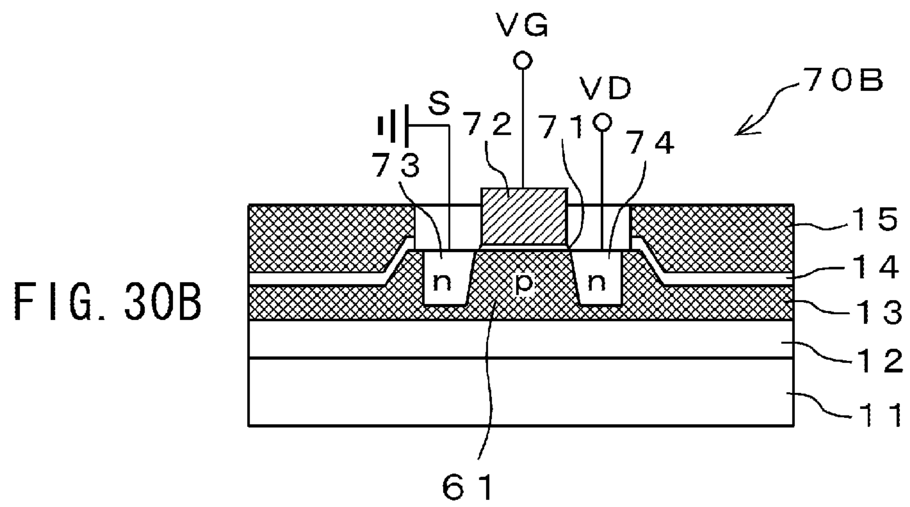


FIG. 30B

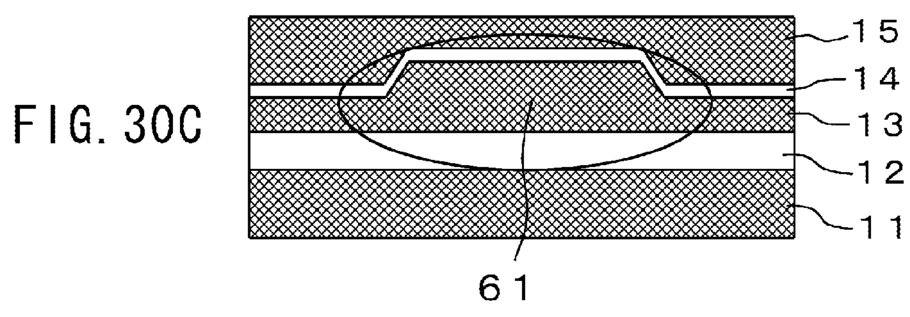


FIG. 30C

FIG. 31A

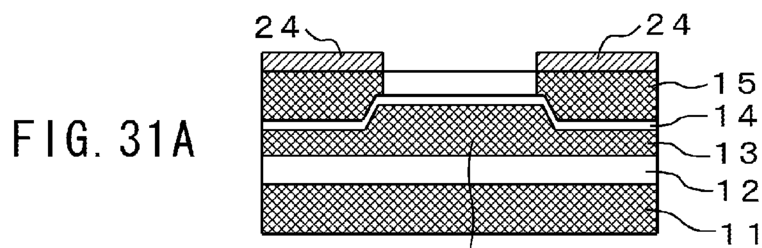


FIG. 31B

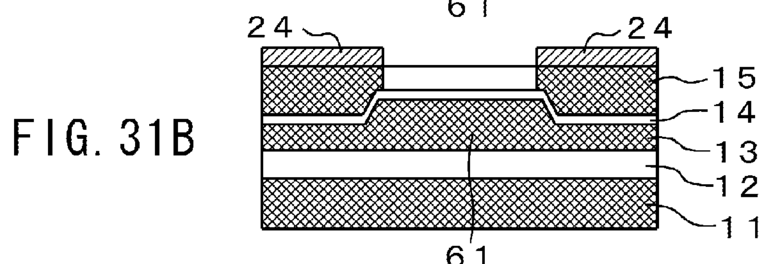


FIG. 31C

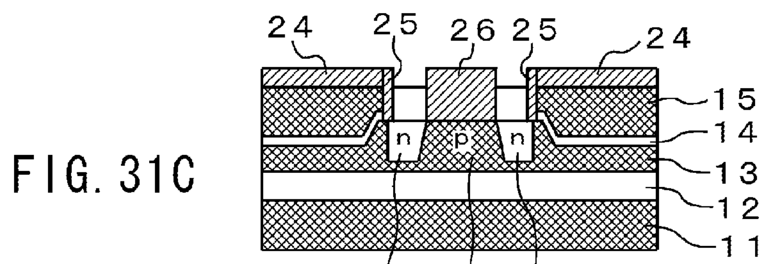


FIG. 31D

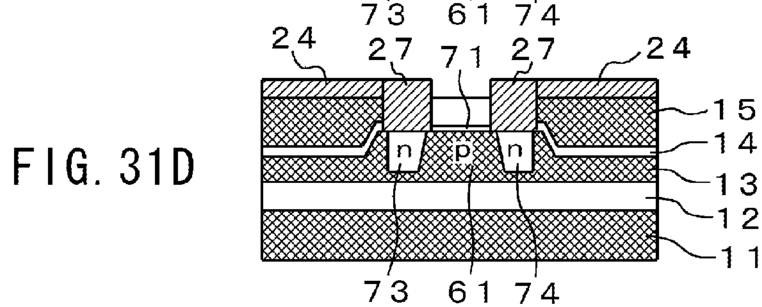


FIG. 31E

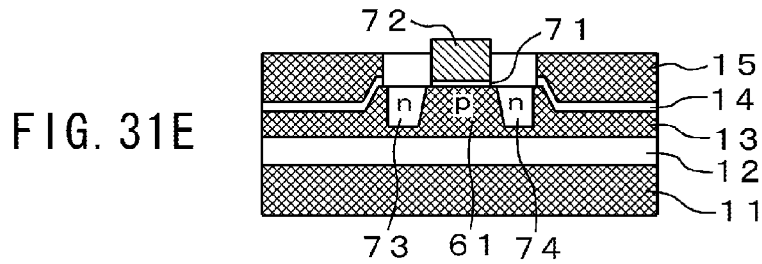


FIG. 31F

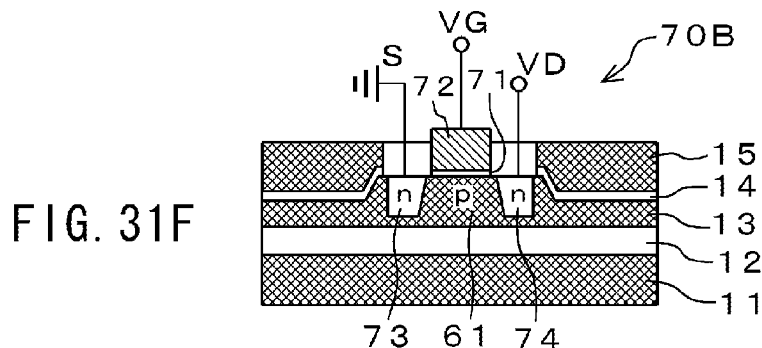


FIG. 32

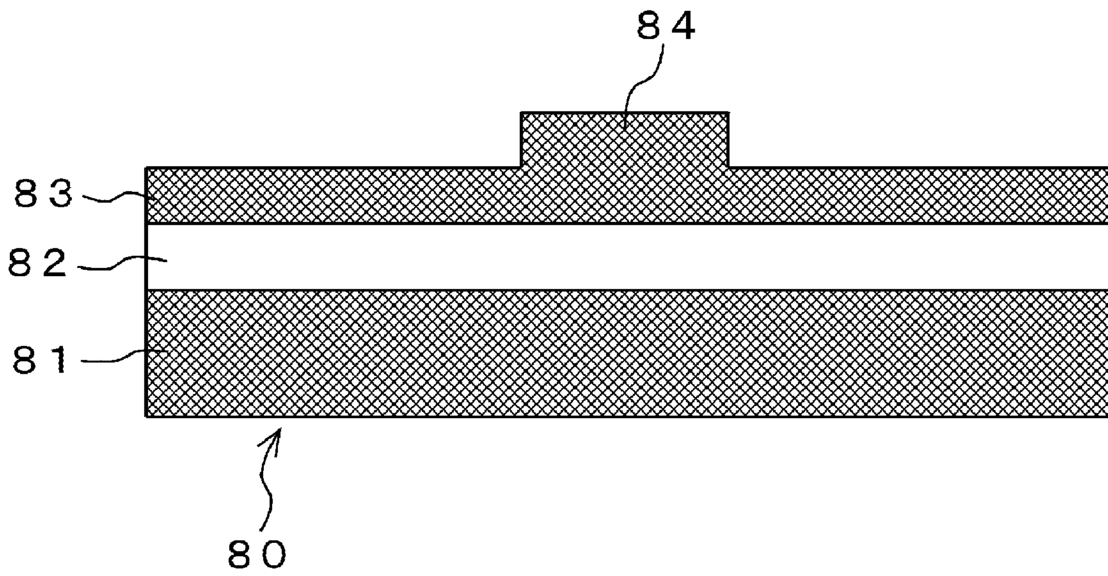
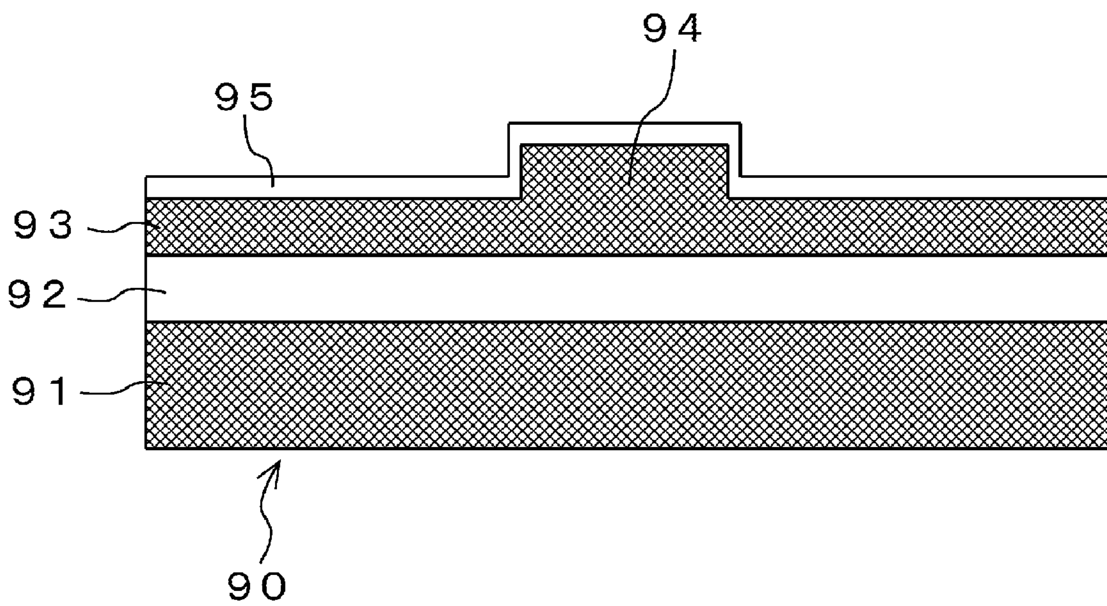


FIG. 33



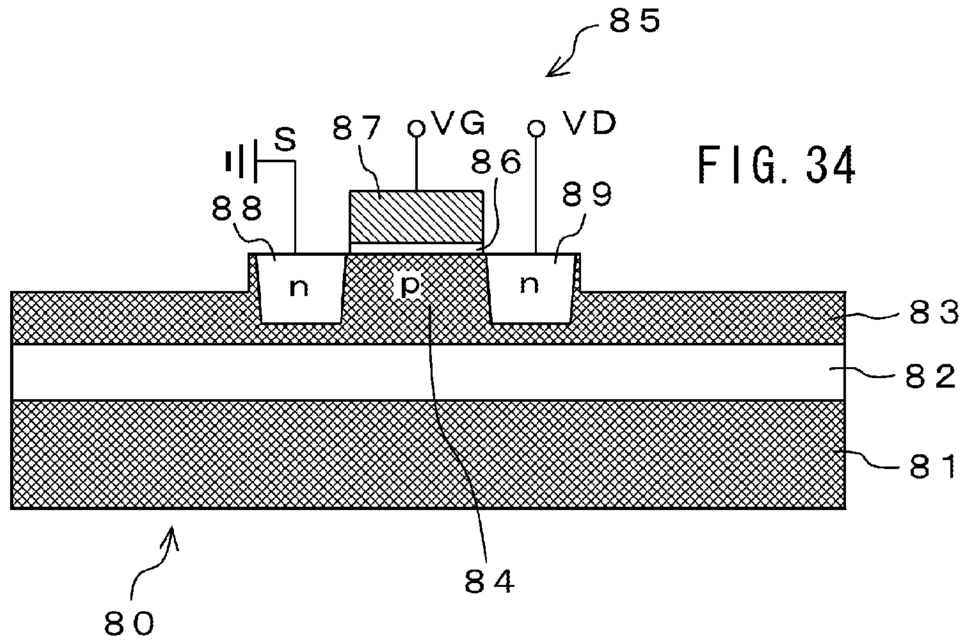


FIG. 34

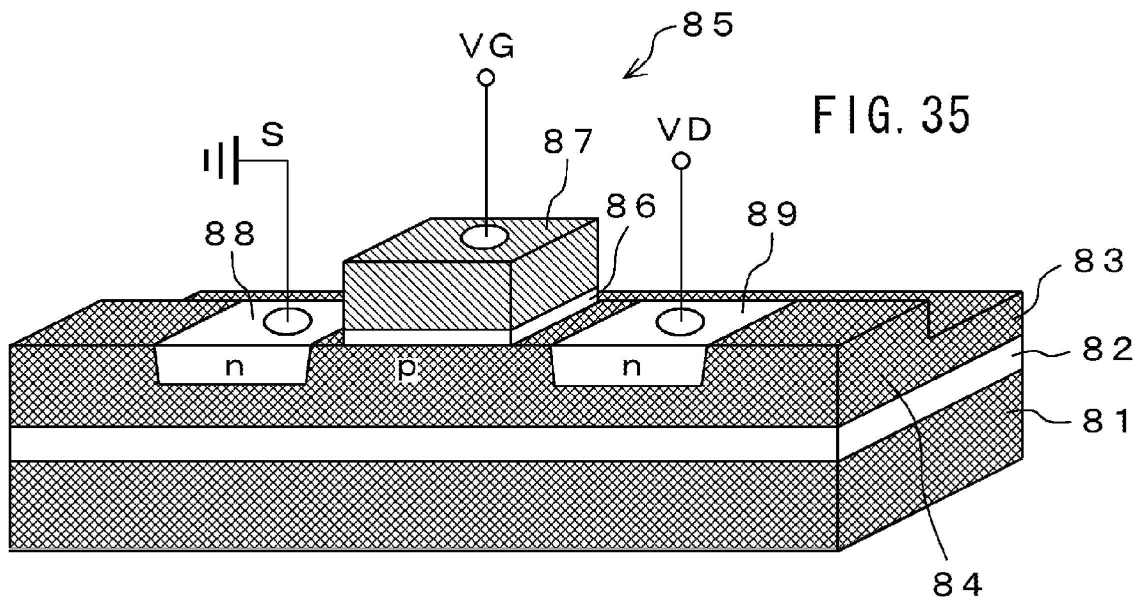


FIG. 35

OPTICAL WAVEGUIDE AND PHOTORECEPTOR

CROSSREFERENCE TO RELATED APPLICATION

The present invention contains subject matter related to Japanese Patent Application JP 2005-339467 filed in the Japanese Patent Office on Nov. 24, 2005, the entire contents of which being incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a semiconductor device having an optical waveguide for performing an optical communication, and a method of detecting light therefor.

2. Description of Related Art

An attempt such that an optical waveguide is formed on a silicon substrate to implement any optical communication capabilities has been recently noted because this enables an optical substrate and an electric substrate to be combined to one chip or an existing manufacturing line for silicon such as a manufacturing line for complementary metal-oxide semiconductor (CMOS) can be utilized, or the like.

Silicon material has transparency on light having a wavelength of 1100 nm or more. This transparency enables light having a band of 1300 nm or 1550 nm, which is used for an optical communication of main line system, to be guided into an optical waveguide, so that the silicon material has been hoped as optical communication parts for which the light having any of these wavelengths is used. In order for the silicon material to be used as the optical communication parts, various kinds of studies for wavelength filter parts, optical amplifier parts, etc. have been carried out.

If a photoreceptor is formed on the silicon substrate, it is necessary to form another material thereon because the silicon material has transparency on light having a wavelength of 1100 nm or more. Thus, a photoreceptor has been often studied in which germanium (Ge) is mainly used as light-absorbing material (see an article, "Increasing penetration of optical transmission into a case of deice: Precedence by a rooter or a portable telephone" of NIKKEI ELECTRONICS published on Jun. 6, 2005, by Tesuo NOZAWA, pages 59 through 70 and FIG. 11 thereof).

SUMMARY OF THE INVENTION

In order to form the photoreceptor employing Ge material on the silicon substrate, however, it is necessary to perform any annealing at about 900 degrees centigrade for about 12 hours at present. This is less suited for manufacturing a device at a low price.

It is desirable to develop a photoreceptor that can be manufactured by applying an existing CMOS manufacturing process thereto as it is. It is also desirable to attain at a low costs a detection of light guided in an optical waveguide that is formed on an insulating layer of the substrate using semiconductor layers thereon.

According to an embodiment of the invention, there is provided a semiconductor device having a substrate that contains an insulating layer and a semiconductor layer provided on the insulating layer. The semiconductor also has an optical waveguide that is formed along a predetermined path. This optical waveguide is formed by making the semiconductor layer non-uniformed in thickness thereof. The semiconductor further has a photoreceptor having metal insulator semiconductor field effect transistor (MISFET) containing a floating channel body that is formed on a position of the semiconductor layer in which electric field of light guided inside the optical waveguide exists and a gate for forming channel formed on a front surface side of the channel body.

In the embodiment of the invention, the substrate that contains an insulating layer and a semiconductor layer provided on the insulating layer, namely, silicon on insulator (SOI) substrate is used. By making the semiconductor layer non-uniformed in thickness along a predetermined path allows the optical waveguide to be formed along this path. The photoreceptor is formed corresponding to a predetermined position (light-receiving position) along a guide direction of this optical waveguide. This photoreceptor is constituted of MISFET containing a floating channel body that is formed on a position of the semiconductor layer in which electric field of light guided inside the optical waveguide stays and a gate for forming channel formed on a front surface of the channel body.

For example, the substrate may include a semiconductor substrate, a first insulating layer formed on the semiconductor substrate, a first semiconductor layer formed on the first insulating layer, a second insulating layer formed on the first semiconductor layer, and a second semiconductor layer formed on the second insulating layer, in this order (double-SOI substrate).

The optical waveguide is formed along the predetermined path by making the first semiconductor layer non-uniformed in thickness thereof. The channel body of the MISFET is formed by the second semiconductor layer or the first semiconductor layer.

For example, the substrate may also include a semiconductor substrate, a first insulating layer formed on the semiconductor substrate, and a first semiconductor layer formed on the first insulating layer, in this order. The optical waveguide is formed along a predetermined path by making the first semiconductor layer non-uniformed in thickness thereof and the channel body of the MISFET is formed by the first semiconductor layer.

For example, the substrate may include a semiconductor substrate, a first insulating layer formed on the semiconductor substrate, a first semiconductor layer formed on the first insulating layer, and a second insulating layer formed on the first semiconductor layer, in this order. The optical waveguide is formed along a predetermined path by making the first semiconductor layer non-uniformed in thickness thereof and the channel body of the MISFET is formed by the first semiconductor layer.

The MISFET detects carrier occurred by two photon absorption (TPA) phenomenon generated when light is guided in the optical waveguide. The MISFET can be manufactured by applying an ordinary CMOS manufacturing process thereto as it is, thereby enabling the light guided in the optical waveguide to be detected at low costs.

For example, the MISFET detects the light guided in the optical waveguide by a cycle of clearing step of removing many carriers remained in the channel body; take-in step of accumulating many carriers corresponding to the light guided in the optical waveguide onto the channel body for a set period of time, after the clearing step; and detection step of detecting the many carriers accumulated onto the channel body, after the take-in step.

If using the double-SOI substrate in which the floating channel body is formed on the first semiconductor layer constituting the optical waveguide, it is possible to increase number of carriers accumulated onto the channel body in the MISFET, as compared by a case where the floating channel

body is formed on the second semiconductor layer that is separated from this first semiconductor layer by means of the second insulating layer. This allows quality of operating frequency as the photodetector to be improved.

For example, a local insulating layer that separates a region of the first semiconductor layer in which the optical waveguide stays from another region of the first semiconductor layer can be provided with the semiconductor device using the double-SOI substrate. This enables respective regions of the first semiconductor layer to be separated from each other, thereby applying most appreciate substrate biased voltage to the respective regions of the first semiconductor layer.

For example, the photoreceptor can be constituted by connecting a plurality of the MISFETs in parallel, which are arranged along a guide direction of the optical waveguide. This allows quality of operating frequency as the photodetector to be improved because total number of carriers is increased in the whole of the plural MISFETs even if less numbers of carriers are accumulated onto a channel body of one MISFET.

Thus, according to the embodiment of the invention, the light guided in the optical waveguide formed by using the semiconductor layer on the insulating layer in the substrate is detected by the photoreceptor having MISFET containing a floating channel body that is formed on a position of the semiconductor layer in which electric field of light guided inside the optical waveguide stays and which corresponds to a predetermined position along a guide direction of the optical waveguide. This enables the light guided in the optical waveguide to be detected at low costs.

The concluding portion of this specification particularly points out and directly claims the subject matter of the present invention. However, those skilled in the art will best understand both the organization and method of operation of the invention, together with further advantages and objects thereof, by reading the remaining portions of the specification in view of the accompanying drawing(s) wherein like reference characters refer to like elements.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is a diagram for showing an example of SOC device to which the invention is applicable;

FIG. **2** is a cross-sectional view of the SOC device having double-SOI substrate structure;

FIGS. **3**A through **3**D are diagrams each for showing a manufacturing step of the double-SOI substrate by means of SIMOX method;

FIGS. **4**A through **4**D are diagrams each for showing a manufacturing step of the double-SOI substrate by means of lamination (polishing) method;

FIGS. **5**A through **5**E are diagrams each for showing a manufacturing step of the double-SOI substrate by means of lamination (Smart-cut) method;

FIG. **6** is a cross-sectional view of FBC memory cell, which is a memory cell constituting DRAM, for showing a configuration thereof;

FIG. **7** is a diagram for showing a cell array in which plural FBC memory cells are arranged in a matrix;

FIG. **8** is a cross-sectional view of FBC memory cell for showing a principle configuration thereof;

FIG. **9** is a graph for showing a relationship between body electric potential and voltage of word line;

FIGS. **10**A and **10**B are diagrams each for showing writing operation into the FBC memory cell;

FIGS. **11**A and **11**B are a diagram and a graph each for showing reading operation out of the FBC memory cell;

FIGS. **12**A through **12**C are graphs each for showing an example of setting of substrate bias voltage when writing or reading data;

FIG. **13** is a diagram for showing separation of regions and region of optical waveguide in order to apply the different substrate bias voltages thereto;

FIG. **14** is a diagram for showing separation of regions in order to apply the different substrate bias voltages thereto;

FIG. **15** is a diagram for showing multi-processor IC;

FIGS. **16**A through **16**E diagrams each for showing a manufacturing step of optical waveguide according to SIMOX method;

FIG. **17** is a perspective view of photoreceptor for showing a whole configuration thereof;

FIG. **18** is a cross-sectional view of the photoreceptor for showing an internal configuration thereof;

FIG. **19** is a diagram for showing a distribution of electric field strength for light;

FIG. **20** is a diagram for showing manufacturing steps of optical waveguide;

FIG. **21** is a diagram for showing hole-storing process during light-receiving operation;

FIG. **22** is a diagram for showing hole-storing process during light-receiving operation;

FIG. **23** is a diagram for showing a clearing step during light-receiving operation;

FIG. **24** is a diagram for showing a clearing step during light-receiving operation;

FIG. **25** is a diagram for showing light-detecting steps during light-receiving operation;

FIG. **26** is a diagram for showing light-detecting steps during light-receiving operation;

FIG. **27** is a graph for showing operation timing of photoreceptor;

FIG. **28** is a graph for showing operation timing of photoreceptor;

FIG. **29** is a cross-sectional view of another embodiment of photoreceptor for showing a configuration thereof;

FIGS. **30**A through **30**C are diagrams each for showing a configuration of further embodiment of photoreceptor;

FIGS. **31**A through **31**F are diagrams each for showing manufacturing step of the photoreceptor;

FIG. **32** is a diagram for showing a configuration of another embodiment of SOI substrate;

FIG. **33** is a diagram for showing a configuration of further embodiment of SOI substrate;

FIG. **34** is a cross-sectional view of still further embodiment of photoreceptor for showing a configuration thereof; and

FIG. **35** is a cross-sectional view of additional embodiment of photoreceptor for showing a configuration thereof.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

The following will describe embodiments of a semiconductor device and a method of detecting light as preferred embodiments of the present invention with reference to drawings. FIG. **1** shows an example of system on chip (SOC) device **100** to which this invention is applicable. This SOC device **100** is a system large scale integrated (LSI) circuit constituted of two central processing units (CPUs) **101**A, **101**B, dynamic random access memory (DRAM) **102**, read only memory (ROM) **103**, logic IC **104**, analog IC **105**, serial I/F unit **106**, parallel I/L unit **107**, and an optical port. In the SOC device, the optical port **108** is connected to an optical fiber **110** to perform a communication to outside.

This SOC device **100** is formed so as to have double-SOI substrate structure **10**. FIG. **2** shows the double-SOI substrate structure **10**. According to the double-SOI substrate structure **10**, a silicon layer (single crystal silicon layer) **13** is formed on a silicon substrate **11** via an insulating layer **12**. A silicon layer (single crystal silicon layer) **15** is formed on this silicon layer **13** via an insulating layer **14**. In this case, the silicon substrate **11** constitutes a semiconductor substrate; the insulating layer **12** constitutes a first insulating layer; the silicon layer **13** constitutes a first semiconductor layer; the insulating layer **14** constitutes a second insulating layer; and the silicon layer **15** constitutes a second semiconductor layer.

Such the double-SOI substrate structure **10** can be manufactured by means of, for example, SIMOX method, lamination (polishing) method, lamination (smart-cut) method, and the like.

The following will describe manufacturing steps of the double-SOI substrate by means of SIMOX method (see FIGS. **3**A through **3**D).

First, an SOI substrate is prepared as shown in FIG. **3**A. This SOI substrate includes the silicon substrate **11**, the insulating layer **12**, for example, silicon oxide layer, provided on the silicon substrate **11**, and a silicon layer **16** provided on the insulating layer **12**. The silicon layer **16** has such thickness that it can be required for an epitaxial growth step and the like.

Next, as shown in FIG. **3**B, oxygen ions with a high energy are implanted into a surface of the silicon layer **16** at a high concentration.

It is then annealed at a high temperature, so that the implanted oxygen ions and the silicon are reacted to produce the insulating layer **14** constituted of silicon oxide layer in the silicon layer **16**, as shown in FIG. **3**C.

Thus, on the silicon substrate **11**, the insulating layer **12**, the silicon layer **13**, the insulating layer **14**, and the silicon layer **15** are formed in this order to produce the double-SOI substrate structure **10**.

Next, as shown in FIG. **3**D, thickness of the silicon layer **15** is adjusted to a desired thickness. For example, the thickness thereof can be increased by an epitaxial growth step while it can be decreased by a formation step of thermally-oxidized film and an etching step.

The following will describe manufacturing steps of the double-SOI substrate by means of lamination (polishing) method (see FIGS. **4**A through **4**D).

First, an SOI substrate is prepared as shown in FIG. **4**A. This SOI substrate includes the silicon substrate **11**, the insulating layer **12**, for example, silicon oxide layer, provided on the silicon substrate **11**, and a silicon layer **16** provided on the insulating layer **12**. A silicon oxide layer **17** is formed on a surface of the silicon layer **13** by means of thermal oxidization. The silicon layer **13** has such thickness that it can be required for an epitaxial growth step and the like.

Alternatively, as shown in FIG. **4**B, a silicon substrate **18** is prepared and a silicon oxide layer **19** is then formed on a surface of the silicon substrate **18** by means of thermal oxidization.

Next, as shown in FIG. **4**C, the SOI substrate prepared in a case shown in FIG. **4**A is laminated with the silicon substrate **18** prepared in a case shown in FIG. **4**B. In this occasion, the silicon oxide layer **19** of the silicon substrate **18** is put over the silicon oxide layer **17** of SOI substrate and the silicon oxide layers **17** and **19** can be adhered to each other by means of hot-pressing.

Further, as shown in FIG. **4**D, thickness of the silicon layer **18** on a surface side thereof is adjusted to a desired thickness by chemical mechanical polishing (CMP). Thus, on the silicon substrate **11**, the insulating layer **12**, the silicon layer **13**, the insulating layer **14**, and the silicon layer **15** are formed in this order to produce the double-SOI substrate structure **10**.

The following will describe manufacturing steps of the double-SOI substrate by means of lamination (Smart-cut) method (see FIGS. **5**A through **5**E).

First, an SOI substrate is prepared as shown in FIG. **5**A. This SOI substrate includes the silicon substrate **11**, the insulating layer **12**, for example, silicon oxide layer, provided on the silicon substrate **11**, and a silicon layer **16** provided on the insulating layer **12**. A silicon oxide layer **20** is formed on a surface of the silicon layer **13** by means of thermal oxidization. The silicon layer **13** has such thickness that it can be required for an epitaxial growth step and the like.

Alternatively, as shown in FIG. **5**B, a silicon substrate **21** is prepared. Hydrogen ions are implanted into the silicon substrate **21** to set a separation position of the silicon substrate **21**.

Next, as shown in FIG. **5**C, the SOI substrate prepared in a case shown in FIG. **5**A is laminated with the silicon substrate **21** prepared in a case shown in FIG. **5**B. In this occasion, a surface of the silicon substrate **21** is put over the silicon oxide layer **20** of SOI substrate and the silicon substrate **21** and the silicon oxide layer **20** can be adhered to each other by means of hot-pressing.

Further, these laminated layers are heated up to such the temperature as to cause the silicon substrate **21** to be separated by concentration of the ion-implanted hydrogen, as shown in FIG. **5**D. Thus, the silicon substrate is separated in two at the separation position thereof.

Additionally, as shown in FIG. **5**E, the separated surfaces of the silicon substrate **21** are polished and finished. Thus, on the silicon substrate **11**, the insulating layer **12**, the silicon layer **13**, the insulating layer **14**, and the silicon layer **15** are formed in this order to produce the double-SOI substrate structure **10**.

In stead of the silicon substrate **18** in the lamination (polishing) method or the silicon substrate **21** in the lamination (Smart-cut) method, a substrate that is composed of germanium, strained silicon, silicon-germanium, or the like can be used to produce a structure similar to the double-SOI substrate structure **10**, thereby enabling such the substrate to be used in stead of the substrate having the double-SOI substrate structure **10**.

In stead of the silicon layer **16** in SIMOX method, a substrate in which a semiconductor layer containing germanium, strained silicon, silicon-germanium, or the like is formed can be used. An insulating layer **14** can be then formed in this semiconductor layer to produce a structure similar to the double-SOI substrate structure **10**, thereby enabling such the substrate to be used in stead of the substrate having the double-SOI substrate structure **10**.

FIG. **6** shows a configuration of FBC memory cell MC constituting DRAM **102** of the above SOC device. As described above, the double SOI substrate in which on silicon substrate **11**, the insulating layer **12**, the silicon layer **13**, the insulating layer **14**, and the silicon layer **15** are formed in this order is used. The silicon layer **15** is p-type silicon layer.

The silicon layer **15** is set as a channel body and a gate electrode **45** is formed on a surface of the silicon layer **15** via gate insulating layer **44**. A source diffusion layer **46** and a drain diffusion layer **47** are formed into a depth reached to the insulating layer **14**. Thus, n-channel MISFET as memory cell MC is configured.

A contact plug **48** composed of polycrystalline silicon (poly-silicon) and the like is plugged into the silicon layer **13** between the insulating layers **12** and **14** with the contact plug passing through the silicon layer **15** and the insulating layer

14. This contact plug 48 is electrically connected to the silicon layer 13. This contact plug 48 is used as bias-voltage-application section for applying substrate-bias-voltage onto the silicon layer 13.

A local insulating layer 49 is also formed between the channel body and the contact plug 48 to prevent the substrate-bias-voltage from being applied from the contact plug 48 to the channel body.

The memory cells MC constituting DRAM 102 are respectively arranged in a matrix by their channel bodies that are floated by isolation to produce a cell array 51, as shown in FIG. 7. In this case, the drain diffusion layer 47 is connected to a bit line BL; the gate electrode 45 is connected to a word line WL; the source diffusion layer 46 is a fixed potential line SL or a ground line; and the contact plug 48 is connected to a substrate bias line VL. It is to be noted that the fixed potential line SL is omitted in the drawings.

To the silicon layer 13 corresponding to each of the memory cells MC, the substrate bias voltage is applied in units of a word line. A local insulating layer 50 extending along a direction of the word line WL are formed to separate the silicon layer 13 corresponding to each of the memory cells MC from one another in units of the word line.

Operations for writing or reading data into or from the memory cell are similar to those of well-known FBC memory cell MC(b) that are formed using an ordinary SOI substrate.

The following will describe a configuration and operations of this FBC memory cell MC(b).

FIG. 8 shows a principle configuration of the FBC memory cell MC(b). In this configuration, SOI substrate in which on a silicon substrate 301, a p-type silicon layer 303 is formed via an insulating layer 302 such as a silicon oxide layer is used.

The silicon layer 303 is set as a channel body and a gate electrode 305 is formed on a surface of the silicon layer 303 via a gate insulating layer 304. A source diffusion layer 306 and a drain diffusion layer 307 are formed into a depth reached to the insulating layer 302. Thus, n-channel MISFET as memory cell MC(b) is configured.

The memory cells MC(b) are respectively arranged in a matrix by their channel bodies that are floated by isolation to produce a cell array. In this case, the drain diffusion layer 307 is connected to a bit line BL; the gate electrode 305 is connected to a word line WL; the source diffusion layer 306 is a fixed potential line or a ground line.

Operation principle of this memory cell MC(b) utilizes storage of hole that includes many carriers in the channel body (p-type silicon layer 303) of MISFET. In other words, when MISFET is operated like pentode by which a large amount of channel current flows through the drain diffusion layer 307, so that impact ionization occurs near a drain junction.

The channel body holds an excess of many carriers (holes) generated by this impact ionization, so that such a state is set as data, for example, "1" while forward current flows between the drain diffusion layer 307 and the channel body and an excess of holes held in the channel body then flows to the drain diffusion layer 307, so that such a state is set as data, "0".

These items of data, "0", "1" indicates difference in potential of the channel body, which are stored as any difference based on a threshold value set in the MISFET. Namely, as shown in FIG. 9, a threshold value Vth1 of the data, "1" in which potential Vbody of the channel body is high based on the hole storage is lower than a threshold value Vth0 of the data, "0" in which potential Vbody of the channel body is low.

In order to hold stable the data, "1" in which the holes are stored in the channel body, it is hopeful to hold voltage VWL to be applied to the word line WL negative. Such the data-holding state remains unchanged even if reading operation occurs unless writing operation of reverse data is accompanied. Namely, it is capable of nondestructive reading unlike DRAM having one transistor/one capacitor by which electric charge holding in the capacitor is used.

The data is basically read out of the memory cells MC(b) by means of detection of difference in conductivities of the memory cells MC(b). Since a relationship between the voltage VWL of word line and the body potential Vbody is shown in FIG. 9, if voltage that lies midway between the threshold values Vth0 and Vth1 of the data, "0" and "1" is applied to the word line WL and it is detected whether or not current flows in the memory cell, the data detection can be attained. Alternatively, if voltage that exceeds the threshold values Vth0 and Vth1 is applied to the word line WL and it is detected how much current flows in the memory cell, the data detection can be also attained.

FIGS. 10A and 10B show writing operation into the memory cell MC(b). FIG. 10A shows writing operation under a condition of data, "1". High positive voltage is applied to the bit line BL (drain diffusion layer) while high positive voltage is applied to the word line WL (gate), so that impact ionization occurs near the drain junction as described above, thereby causing holes to be stored in the channel body. FIG. 10B shows writing operation under a condition of data, "0". Negative voltage is applied to the bit line BL (drain diffusion layer) while high positive voltage is applied to the word line WL (gate), so that p-n junction between the channel body (p-type silicon layer 303) and the drain diffusion layer 307 is forward-biased, thereby causing holes to be flown out of the channel body 303.

FIGS. 11A and 11B show reading operation out of the memory cell MC(b). FIG. 11A shows reading operation under conditions of data, "0" and "1". Low positive voltage is applied to the bit line BL (drain diffusion layer) while high positive voltage is applied to the word line WL (gate), thereby preventing the data from be destroyed by impact ionization. FIG. 11B shows a relationship between drain current Ids and gate voltage Vgs when reading. For example, voltage VWL-read that exceeds the threshold values Vth0, Vth1 is applied to the word line WL and sense amplifier detects difference ΔIds (=I1−I0) in drain currents corresponding to the difference in the threshold values Vth0 and Vth1, thereby allowing the data, "0" and "1" to be identified.

The following will describe substrate bias voltage to be applied to the silicon layer 13 corresponding to each of the memory cells MC that constitutes DRAM 102.

When writing no data and reading no data, the substrate bias voltage to be applied to the silicon layer 13 (voltage to be applied to the substrate bias line VL) is set to a first value, for example, −1 V, which can restrain decrease in numbers of holes, namely, carriers, stored in the channel body. This first value is a value of voltage such that it is hard to generate any phenomenon to decrease numbers of holes stored in the channel body (pass-gate leakage phenomenon) even if voltage alters at the bit line (drain diffusion layer) BL when writing or reading data of another portion.

When writing data and reading data, the substrate bias voltage to be applied to the silicon layer 13 is set to any one of the following three options (1), (2), and (3):

(1) When writing items of data, "1" and "0", as shown in FIG. 12A, the substrate bias voltage to be applied to the silicon layer 13 is set to a second value, for example, 0 V, that is suitable for writing;

(2) When writing data, “1”, as shown in FIG. **12**B, the substrate bias voltage to be applied to the silicon layer **13** is set to a second value, for example, 0 V, that is suitable for writing;

(3) When writing and reading data, as shown in FIG. **12**C, the substrate bias voltage to be applied to the silicon layer **13** is set to a second value, for example, 0 V, that is suitable for writing.

On these options (1) and (2), the substrate bias voltage is set to the first value, for example 0 V, which can restrain decrease in numbers of holes stored in the channel body except for a period of time when writing items of data, “1” and “0” or when writing data, “1”. This permits any pass-gate leakage phenomenon to be harder to occur even if voltage alters at bit line BL (drain diffusion layer), as compared with a case where the substrate bias voltage is set to the second value.

Further, on these options (1) and (2), when writing items of data, “1” and “0” or when writing data, “1”, the substrate bias voltage is set to the second value that is suitable for writing. This enables voltage of the bit line BL when writing data to be set lower, thereby allowing any pass-gate leakage phenomenon to be harder to occur at a location connecting to the word line WL, where data is prohibited from being written.

On the option (3), as compared with the options (1) and (2), a long period of time when the substrate bias voltage is not held to a value which can keep numbers of holes stored in the channel body is lapsed. According to the option (3), however, it is possible to set a changeover frequency of the substrate bias voltage to strikingly low one, as compared with the options (1) and (2).

It is assumed that the insulating layer **14** is formed by means of SIMOX method or lamination method so that the insulating layer can be generally formed thicker than the gate oxide layer **44** is formed, this option (3) is seemed to be application method of substrate bias voltage that is suitable for implementing a high speed record-and-reproduction.

In the SOC device **100** shown in FIG. **1**, a local insulating layer **55** for separating the silicon layer **13** one from another is provided between the regions in the silicon layer **13**, to which different substrate bias voltages are to be applied. FIG. **13** shows regions A and B and region of optical waveguide, which will be described. FIG. **14** shows regions of N channel and P channel.

In these cases, a local insulating layer **55** for separating the silicon layer **13** one from another is provided between the respective regions. Through a contact plug **56** that is formed similar to the contact plug **48** in the memory region, predetermined substrate bias voltage can be applied to each of the regions. This enables most suitable substrate bias voltage to be applied to each of the regions of silicon layer **13**, thereby allowing the highest performance to be attained in the SOC device **100**.

It is to be noted that although the SOC device **100** shown in FIG. **1** has been provided with two CPUs, **101**A, **101**B, the invention is not limited thereto. For example, as shown in FIG. **15**, multi-processor IC having six processors, MPU**1** through MPU**6** is conceivable. In this IC, all of the processors are not active (set on) anytime. For example, specially when one high definition (HD) image is simply decoded, IC is active but all of the processors therein are not active.

In this case, if active processors are illustratively the processors MPU**1** and MPU**2**, substrate bias voltage that is most suitable when operating can be applied to regions of these processors MPU**1** and MPU**2** whereas substrate bias voltage that is most suitable when waiting can be applied to regions of other processors MPU**3** through MPU**6**.

Further, in the SOC device **100** shown in FIG. **1**, optical communication can be performed between, for example, CPU **101**A and CPU **101**B using an optical waveguide. In this embodiment, as shown in FIG. **13**, the optical waveguide **61** for optical communication is constituted of the insulating layer **12**, the silicon layer **13**, and the insulating layer **14**. In this embodiment, uneven portion of the silicon layer **13** as the optical waveguide **61** is formed in the silicon layer **13** sandwiched between the insulating layers **12**, **14**. Silicon (Si) has refractive index of 3.5 and silicon dioxide (SiO_2) has refractive index of 1.5, so that the optical waveguide **61** can be constituted of the insulating layer **12**, the silicon layer **13**, and the insulating layer **14**.

The following will describe manufacturing steps of the optical waveguide **61** in a case where it is manufactured according to SIMOX method with reference to FIG. **16**. In FIG. **16**, like reference characters refer to like elements shown in FIG. **3**, detailed explanation of which will be omitted.

First, an SOI substrate is prepared as shown in FIG. **16**A. This SOI substrate includes the silicon substrate **11**, the insulating layer **12**, for example, silicon oxide layer, provided on the silicon substrate **11**, and a silicon layer **16** provided on the insulating layer **12**. The silicon layer **16** has such thickness that it can be required for an epitaxial growth step and the like.

Next, as shown in FIG. **16**B, a silicon oxide layer **22** is formed on a surface of the silicon layer **16** by means of thermal oxidization. Any pattering is performed on the silicon oxide layer **22**, so that a mask **23** of silicon dioxide corresponding to the optical waveguide **61** can be formed, as shown in FIG. **16**C.

Next, as shown in FIG. **16**D, oxygen ions are implanted into a surface of the silicon layer **16** with the mask **23** being positioned thereon. In this moment, at a location on which the mask **23** is positioned, the mask **23** decreases a speed of oxygen ion, thereby implementing the oxygen ions shallower whereas at a location on which no mask is positioned, the mask **23** does not decrease a speed of oxygen ion, thereby implementing the oxygen ions deeper.

As shown in FIG. **16**E, SOI substrate, to the silicon layer **16** of which oxygen ions are implemented, is then annealed at a high temperature, so that the implanted oxygen ions and the silicon are reacted to produce the silicon oxide layer (insulating layer) **14** in the silicon layer **16**.

Thus, the insulating layer (silicon oxide layer) **12**, the silicon layer **13**, and the insulating layer (silicon oxide layer) **14** are formed in this order to produce the optical waveguide **61**. It is to be noted that the mask **23** is removed therefrom after or before annealing or after a certain degree of annealing is carried out.

The SOC device **100** shown in FIG. **1** is also provided with a photoreceptor **70** for detecting an optical signal guided through the above-mentioned optical waveguide **61**. FIGS. **17** and **18** show a configuration of the photoreceptor **70**. FIG. **17** shows a whole configuration thereof and FIG. **18** shows a cross section thereof.

This photoreceptor **70** has MOS transistor (PDSOI transistor) as MISFET, which is set on a location corresponding to a predetermined location of the optical waveguide **61**. In this case, p-type silicon layer **15** is set as channel body and on a surface thereof, a gate electrode **72** is formed via a gate insulating layer **71**. A source diffusion layer **43** and a drain diffusion layer **74** are also formed toward a depth reached to the insulating layer **14**. Thus, PDSOI transistor is configured.

An ordinary photoreceptor operates based on a principle of detecting current generated by reception of photon and thus, can perform consecutive measure of an amount of light. A principle of receiving light in the photoreceptor **70** is based on detection whether or not TPA phenomenon generated by

light-guiding just before the detection occurs. The amount of light is not consecutively monitored in the photoreceptor **70** and a cycle of this measurement is almost two cycles of MOS transistor, thereby enabling high-speed MOS device to be manufactured and very rapid response detection of the amount of light to be implemented.

When the optical waveguide **611** guides light, a large amount of light (evanescent light) propagating into a portion upon this optical waveguide **61** is present therein. This causes electric field of light guided in the optical waveguide **61** to be existed in the channel body of the PDSOI transistor constituting the photoreceptor **70**. In the photoreceptor **70**, TPA phenomenon generated by this propagating light is utilized.

FIG. **19** shows, in the optical waveguide **61** formed in a size shown in FIG. **20**, a distribution of electric field strength for light having a wavelength of 1.55 μm that is guided in the optical waveguide **61**. As clearly shown in FIG. **19**, it is seen that a large amount of light (evanescent light) propagating into a portion upon this optical waveguide **61** is present therein. It is to be noted that a unit of size of each of layers shown in FIG. **20** is μm.

The following will describe a principle of receiving light in the photoreceptor **70**.

As described above, the photoreceptor **70** is based on detection whether or not TPA phenomenon generated by light-guiding in the optical waveguide **61** just before the detection occurs. This occurrence of TPA phenomenon is detected on the basis of existence or nonexistence of the hole stored in the channel body.

The following will describe process in which holes are stored in the channel body of the PDSOI transistor, namely, the photoreceptor **70** based on TPA phenomenon of light guided in the optical waveguide **61** with reference to FIGS. **21**, **22**.

First, as shown in FIG. **21**, a pair of electron and hole is formed by TPA phenomenon at a region in which there is an electric field of light. At first, electrons and holes exist equal in number. Since traveling speed of electron has several times as rapid as that of the hole and thus, the electron can be easily traveled as compared with the hole, the electron is rapidly and easily reached to the source diffusion layer **73** and the hole remains in the channel body.

The following will describe clearing step performed just before the light-detecting steps with reference to FIGS. **23** and **24**.

The photoreceptor **70** detects the hole remained in the channel body of the PDSOI transistor, as described above, and it is necessary to provide a step (hereinafter, referred to as "clearing step) for removing the hole that may remain in the channel body just before the light-detecting steps are performed.

In order to remove the hole from the channel body in the clearing step, drain voltage VD of PDSOI transistor is set to negative voltage, for example, −1 V, so that forward p-n junction occurs therein and the hole remained in the channel body is then forcibly traveled to the drain diffusion layer **74**.

FIG. **23** shows the clearing step when no light is guided in the optical waveguide **13** (**61**). In this case, almost holes remained in the channel body can be perfectly removed. FIG. **24** shows the clearing step when light is guided in the optical waveguide **13** (**61**), namely, TPA phenomenon occurs. In this case, TPA phenomenon generates carriers one after another in the channel body but almost electrons can be traveled to the source diffusion layer and almost holes can be traveled to the drain diffusion layer.

The following will describe light-detecting steps with reference to FIGS. **25** and **26**. The photoreceptor **70** does not determine whether light is guided in the optical waveguide **61** at a detection period of time, but determines whether a period of time when light is guided during a period of time starting from a finish of the above clearing step to a detection time is long or not.

FIG. **25** shows an example of a case where a period of time when light is guided during a period of time starting from a finish of the above clearing step to a detection time is long. In this example, at the detection time, the holes generated by means of TPA phenomenon during a period of time starting from a finish of the above clearing step to the detection time remain in the channel body of PDSOI transistor that is the photoreceptor **70**. It is determined therefrom that the period of time when light is guided during a period of time starting from a finish of the above clearing step to a detection time is long.

In order to determine whether or not the holes remain in the channel body, gate voltage VG is set to positive voltage, for example, 1.3 V. When voltage is being gradually applied to the drain diffusion layer **74**, change in drain current is detected, thereby determining whether or not the holes remain in the channel body. This equals to reproduction principle in the above FBC memory cell.

FIG. **26** shows an example of a case where a period of time when light is guided during a period of time starting from a finish of the above clearing step to a detection time is very short. In this example, at the detection time, almost holes generated by means of TPA phenomenon during a period of time starting from a finish of the above clearing step to the detection time not remain in the channel body of PDSOI transistor that is the photoreceptor **70**. It is determined therefrom that the period of time when light is guided during a period of time starting from a finish of the above clearing step to a detection time is very short.

The following will describe operation timings of the photoreceptor (PDSOI transistor) **70** with reference to FIGS. **27** and **28**. FIG. **27** shows an example of drain current if no hole remain in the channel body by avoiding light being guided in the optical waveguide **61** during a period of acquiring time after a finish of the clearing step. FIG. **28** shows an example of drain current if the hole remains in the channel body by guiding light in the optical waveguide **61** during a period of acquiring time after a finish of the clearing step.

As shown in FIGS. **27** and **28**, operations of the photoreceptor **70** include three steps constituted of clearing step, acquiring step and reading step. Such the few steps of three steps can cause its operation frequency to be reduced to a frequency that is smaller than response frequency of PDSOI transistor (MOS transistor) incomparably. This means less deterioration in frequency. If PDSOI transistor has operation frequency of about 10 G Hz, this transistor can have operation frequency of an order of some G Hz.

Although it is necessary that numbers of the holes increases to enhance an accuracy of detection in order to improve performance relative to operation frequency, when numbers of the holes increases by extending a period of data-acquiring time, repeat rate of cycles decreases, which does not improve performance relative to operation frequency. Further, even when numbers of the holes increases by increasing a space between gates to expand the channel body, operation frequency of PDSOI transistor deteriorates. This shortens a period of data-acquiring time, but does not shorten a period of cycle.

FIG. **29** shows an example of improvement of performance relative to operation frequency as the photodetector. FIG. **29** shows a photoreceptor **70**A that is capable of shortening a period of data-acquiring time and increasing an amount of signal as a result thereof by increasing numbers of the holes

without increasing a space between gates. In FIG. **29**, like reference characters refer to like elements shown in FIGS. **17** and **18**, detailed explanation of which will be omitted.

This photoreceptor **70**A is configured so that plural PDSOI transistors, four transistors in a case shown in FIG. **29**, can be arranged along a guide direction of the optical waveguide **61** and can be connected in parallel to each other.

According to the photoreceptor **70**A, an area of channel body can be practically expanded so that numbers of the holes existed in the channel body can increase, thereby improving performance relative to operation frequency as photodetector.

Refractive index of Si material is about 3.5. If it is estimated that effective refractive index of light guided in the optical waveguide made of Si material is three, light is guided about 10 cm for a period of time of 1 nsec. Thus, as a principle, if the photoreceptor **70**A is configured so that plural PDSOI transistors are arranged in an area having a length of 10 cm or less, this photoreceptor **70**A can detect signal of some G Hz.

The photoreceptor in which plural PDSOI transistors are arranged in parallel may have increased leakage current(s) to deteriorate signal quality, so that number of PDSOI transistors to be connected can be limited. The embodiment, however, demonstrates that it is not particularly restricted by only operation frequency, so that if only practical number of PDSOI transistors (for example, less than 100 transistors) are arranged along a guide direction of the optical waveguide **61** and they are electrically connected in parallel to each other to produce a photoreceptor, such the photoreceptor is very effective device for shortening data-acquiring period of time.

Although, in FIG. **29**, it has been shown that plural PDSOI transistors are arranged along a guide direction of the optical waveguide **61** in a line, this invention is not limited to this arrangement. For example, they can be arranged in plural lines or at random. It, however, is necessary that plural PDSOI transistors may be arranged in any locations corresponding to locations in the optical waveguide **61** where carriers occur by means of TPA phenomenon by light guided in the optical waveguide **61** and holes remain therein.

FIGS. **30**A through **30**C shows a configuration of another embodiment of the photoreceptor **70**B that is capable of improving performance relative to operation frequency as the photodetector. FIG. **30**A shows a whole configuration thereof; FIG. **30**B shows a cross section thereof taken along lines A-A shown in FIG. **30**A; and FIG. **30**C shows a cross section thereof taken along lines B-B shown in FIG. **30**A. In this embodiment, the photoreceptor **70**B can increase numbers of the holes without increasing a space between gates and consequently shorten a data-acquiring period of time to increase an amount of signal. In FIGS. **30**A through **30**C, like reference characters refer to like elements shown in FIG. **18**, detailed explanation of which will be omitted.

Relating to a forming location of the photoreceptor **70**B, a rectangle portion is removed from the insulating layer **14** and the silicon layer **15**. A channel body of PDSOI transistor (MOS transistor) constituting the photoreceptor **70**B is formed in the silicon layer **13** constituting a core of the photoreceptor **61**.

The following will describe manufacturing steps of the photoreceptor **70**B.

First, a resist pattern **24** having an opening at a portion thereof corresponding to a location in which the photoreceptor **70**B is to be formed is formed as shown in FIG. **31**A. A portion of the silicon layer **15**, which corresponds to a location in which the photoreceptor **70**B is to be formed, is removed therefrom by means of etching.

Next, as shown in FIG. **31**B, using the resist pattern **24**, a portion of the insulating layer **14**, which corresponds to a location in which the photoreceptor **70**B is to be formed, is removed therefrom by means of etching.

Further, as shown in FIG. **31**C, a resist pattern **25** is formed to prevent p-type impurity ion and n-type impurity ion form being implanted into the silicon layer **15**. Then, the p-type impurity ion is implanted into the silicon layer **13** to produce p-type silicon layer. A resist pattern **26** is formed on a portion of the silicon layer **13** corresponding to the channel body. The n-type impurity ion is then implanted into the silicon layer **13** to produce source diffusion layer **73** and drain diffusion layer **74**.

As shown in FIG. **31**D, the resist patter **26** is then removed therefrom, as well as resist patterns **27** are formed on the source diffusion layer **73** and the drain diffusion layer **74** and gate insulating layer **71** is also formed corresponding to the channel body.

Next, as shown in FIG. **31**E, the resist patterns **27** are removed and a gate electrode **72** made of polysilicon is formed on the gate insulating layer **71**. As shown in FIG. **31**F, electrodes are respectively connected to the source diffusion layer **73**, the drain diffusion layer **74**, and the gate electrode **72** to produce the photoreceptor **70**B.

According to the photoreceptor **70**B, the channel body of the PDSOI transistor is formed on the silicon layer **13** constituting the core portion of the optical waveguide **61**, so that an area of the channel body can be expanded to increase number of the holes existed in the channel body, thereby allowing performance relative to operation frequency as the photodetector to be improved.

As described above, the photoreceptors **70**, **70**A, and **70**B respectively have PDSOI transistor(s) that has (have) the floating channel body formed on the silicon layer **15** or **13** and a gate (gate electrode **72**) for forming a channel that is formed on a surface side of the channel body, so that an ordinary process of manufacturing CMOS can be applied to this manufacture process of the photoreceptors as it is. This attains detection of light guided in the optical waveguide **61** at low price.

Although, in the photoreceptors **70**, **70**A shown in FIGS. **18** and **29**, it has been shown that these photoreceptors **70**, **70**A have MOS structure such that n-p-n structure of PDSOI transistor constituting each of the photoreceptors **70**, **70**A can be arranged along a longitudinal direction of the optical waveguide **61** (light-guide direction), these photoreceptors **70**, **70**A may have MOS structure such that the n-p-n structure of PDSOI transistor can be arranged along a direction that is perpendicular to the longitudinal direction of the optical waveguide **61**.

Similarly, although, in the photoreceptor **70**B shown in FIGS. **30**A through **30**C, it has been shown that the photoreceptor **70**B has MOS structure such that n-p-n structure of PDSOI transistor constituting the photoreceptor **70**B can be arranged along a direction that is perpendicular to the longitudinal direction (light-guide direction) of the optical waveguide **61**, the photoreceptor **70**B may have MOS structure such that the n-p-n structure of PDSOI transistor can be arranged along a longitudinal direction of the optical waveguide **61**.

Although, in these above-mentioned embodiments, the optical waveguide **61** has been formed so that the silicon layer **13** sandwiched between double insulating layers **12** and **14** can have uneven portion extending along a predetermined path and light guided in the optical waveguide **61** can be detected by the PDSOI transistor, this invention is not limited to this. It also can be generally applied to a case where light guided in the optical waveguide **61**, in which semiconductor

layer (silicon layer) formed on the insulating layer of the substrate has uneven portion extending along a predetermined path, is detected.

For example, as shown in FIGS. **32** and **33**, I embody SOI substrates **80** and **90** each having an optical waveguide.

The following will describe the SOI substrate **80** shown in FIG. **32**. This SOI substrate **80** has a configuration such that silicon layer (single crystal silicon layer) **83** is formed on a silicon substrate **81** via an insulating layer (silicon oxide layer) **82**. The silicon layer **83** is etched to have uneven portion extending along a predetermined path, thereby enabling the optical waveguide **84** to be formed. It is to be noted that the silicon substrate **81** constitutes semiconductor substrate; the insulating layer **82** constitutes first insulating layer; and the silicon layer **83** constitutes first semiconductor layer.

The following will describe the SOI substrate **90** shown in FIG. **33**. This SOI substrate **90** has a configuration such that silicon layer (single crystal silicon layer) **93** is formed on a silicon substrate **91** via an insulating layer (silicon oxide layer) **92**. The silicon layer **93** is etched to have uneven portion extending along a predetermined path, thereby enabling the optical waveguide **94** to be formed. Silicon oxide layer **95** covers the optical waveguide **94**. It is to be noted that the silicon substrate **91** constitutes semiconductor substrate; the insulating layer **92** constitutes first insulating layer; the silicon layer **93** constitutes first semiconductor layer, and the silicon oxide layer **95** constitutes second insulating layer.

This invention can be applied to a case where light guided in any of the optical waveguides **84**, **94** of the SOI substrates **80**, **90** shown in FIGS. **32**, **33** is detected. In other words, relative to the SOI substrate **80**, as shown in FIGS. **34**, **35**, by forming MOS transistor (PDSOI transistor) as the photoreceptor **85** corresponding to a predetermined position along a guiding direction of the optical waveguide **84**, it is possible to detect light guided in the optical waveguide **85**. In this case, p-type silicon layer **83** is set as channel body and gate electrode **87** is formed on a surface of the p-type silicon layer **83** via gate insulating layer **86**. Source diffusion layer **88** and drain diffusion layer **89** are formed so as to have a depth reached to the insulating layer **82**. Thus, PDSOI transistor can be configured. Although detailed explanation thereof will be omitted, operations for detecting light in the photoreceptor **85** are similar to those for the above photoreceptor **70** (see FIGS. **17** and **18**).

In the photoreceptor **85** shown in FIG. **34**, it has been shown that the photoreceptor **85** have MOS structure such that n-p-n structure of PDSOI transistor constituting the photoreceptor **85** can be arranged along a direction that is perpendicular to a longitudinal direction (light-guide direction) of the optical waveguide **84**. In the photoreceptor **85** shown in FIG. **35**, it has been shown that the photoreceptor **85** have MOS structure such that the n-p-n structure of PDSOI transistor constituting the photoreceptor **85** can be arranged along a longitudinal direction of the optical waveguide **84**.

Relative to the SOI substrate **90**, similar to the above SOI transistor **80**, by forming PDSOI transistor as the photoreceptor corresponding to a predetermined position along a guiding direction of the optical waveguide **94** (see FIGS. **34** and **35**), it is possible to detect light guided in the optical waveguide **94**.

Although it has been shown in the above embodiments that PDSOI transistor is positioned on clad portion (see FIG. **17**) or core portion (see FIGS. **30**, **34**, **35**) of each of the optical waveguides **61**, **84**, **94**, PDSOI transistor can be positioned on any portion where carriers occur by TPA phenomenon and holes remain therein (a position in which electric field of light guided in an optical waveguide exists).

Although the optical waveguide **61** of double-SOI substrate **10** has been manufactured by means of SIMOX method in the above embodiments, such the optical waveguide **61** can be manufactured by another method.

According to the above embodiment of the invention, it is possible to detect light guided in the optical waveguide formed on the semiconductor substrate at low price. Thus, this invention can be applied to a semiconductor device in which optical communication is performed between or among desired functional devices. It should be understood by those skilled in the art that various modifications, combinations, sub-combinations and alternations may occur depending on design requirements and other factors insofar as they are within the scope of the appended claims or the equivalents thereof.

What is claimed is:

1. A semiconductor device comprising:

a substrate that contains a semiconductor substrate, a first insulating layer formed on the semiconductor substrate, a first semiconductor layer formed on the first insulating layer, a second insulating layer formed on the first semiconductor layer, a second semiconductor layer formed on the second insulating layer, a gate insulating layer formed on the second semiconductor layer, and a gate electrode layer formed on the gate insulating layer, in this order;

an optical waveguide that is formed along a predetermined path, said optical waveguide being formed by making the first semiconductor layer non-uniformed in thickness thereof; and

a photoreceptor having MISFET containing a floating channel body that is formed by the second semiconductor layer on a position of the first semiconductor layer in which electric field of light guided inside the optical waveguide exists and a gate for forming channel formed on a front surface side of the channel body.

2. The semiconductor device according to claim **1**, further comprising a local insulating layer that separates a region of the first semiconductor layer in which the optical waveguide is formed from another region of the first semiconductor layer.

3. The semiconductor device according to claim **1** wherein the photoreceptor is constituted by connecting a plurality of the MISFETs in parallel, said MISFETs being arranged along a guide direction of the optical waveguide.

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